tree planting practices in african savannas

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

This manual on savanna afforestation practices in Africa appears in response to the need for economic development in the region to support a rapidly rising population. Increasing emphasis must be placed on the development of the savanna, to increase its productivity and improve its effectiveness as a protective agent. While the manual does not pretend to be exhaustive, it is hoped that it will provide some practical guidance to those attempting savanna afforestation as well as stimulating research in the study and development of savanna resources.

TREE PLANTING PRACTICES IN AFRICAN SAVANNAS

Clean-weeding is essential for successful establishment of eucalyptus in savanna. This picture shows mechanical weeding between rows of young *Eucalyptus* "*grandis*" in Zambia. A termite mound, carrying natural vegetation and excluded from the land clearing operation, can be seen in the background.

(*Courtesy* Forest Department, Zambia)

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FOREWORD

This study, prepared by Professor M.V. Laurie, the late Professor of Forestry in the University of Oxford, forms one of the series of publications dealing with tree planting practices in different geographical regions of the world. The importance of tree planting in African savannas was recognized by the FAO African Forestry Commission at its first session in Nigeria in 1960. A summary of information on this subject was contained in the Commission's draft report on savanna afforestation in Africa (1966), to which the main contributors were F. Rittershofer and W.E.M. Logan. The present study, though based on the earlier report, has been largely rewritten and expanded to include new data and experience.

Valuable information and comments have been contributed by many foresters working in African savannas, whose assistance is gratefully recorded. Special acknowledgement is made to D. Greenwood, T. Allan and J.K. Jackson for their comments on the final draft. Thanks are also due to the Forest Departments and individuals who kindly provided photographs or maps.

R.G. Fontaine
Director, Forest Resources Division

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INTRODUCTION

The policy of all African governments is to develop their countries economically and to raise the standard of living of their people. Already considerable progress has been made toward these ends and this progress is likely to be accelerated in the future. At the same time populations throughout Africa are increasing and in some countries are expected to double before the end of the century.

These factors, economic development, rising standards of living and increasing population, will generate further demands for forest produce of all kinds. At the same time, there will be more pressure on the land for agriculture and stock raising, and on water resources.

The area of savanna (in the broad sense, see p. 6) in Africa is slightly less than one half of the total area of the continent; in comparison the high forest covers only about one twelfth. The cruder kinds of forest produce, such as firewood and poles, are commodities which it is not normally economic to transport long distances. Moreover, most of the inhabitants of the savanna regions are not wealthy and are unlikely to achieve a high level of wealth in the foreseeable future. Therefore, they will probably not be in a position to import any great quantities of even the basic kinds of forest produce from other areas, especially if lengthy hauls are entailed, and will be obliged to rely on the resources of their own savanna woodlands.

At the best of times, these natural savanna woodlands are sparsely stocked and low yielding and, more often than not, have suffered from overcutting in the past. Near the larger towns and centres of population tree growth may have virtually disappeared. Acute local shortages of wood are already being experienced in these areas.

To meet the demand for forest produce which is expected to grow appreciably over the next few decades, and to provide for more effective protection of water catchments and better soil stabilization, considerable development of the savanna woodland resources will be required. Hitherto, forest development has been mainly concentrated in the closed high-forest zone. But, for the reasons outlined above, the time is now approaching, and indeed in many countries has already arrived, when more emphasis must be placed on the development of savanna woodland, with the dual aims of increasing its productivity and improving its effectiveness as a protective agent. On the productive side, savanna afforestation is likely to be principally a matter of special-purpose plantations designed to meet particular local needs.

The need for such development of the savanna was recognized by the FAO African Forestry Commission at its first session held in Nigeria in 1960. Because of the low productivity of the savanna in its natural state, it was also established that any appreciable increase in productivity must in the main be effected by means of planting. Subsequently, to stimulate the study of savanna afforestation, the then Forestry and Forest Products Division of FAO, *inter alia*, arranged the preparation of a report on savanna afforestation practices.

This report was compiled and circulated in 1966 (FAO. African Forestry Commission, 1966) and forms the basis for this manual. Recent reports from African savanna countries, summarizing research results and plantation experience in the last four years, have been incorporated and the whole brought up to date as far as possible. The major sources of further information were Zambia, where recent research and plantation practice have shown considerable advances (Allan, 1967a; Allan and Endean, 1966; Cooling and Endean, 1966), and FAO-sponsored research into savanna afforestation in Sudan (FAO, 1969b), and at the Savanna Forestry

Research Station at Samaru in northern Nigeria (FAO, 1970a).

This manual does not pretend to be exhaustive. Much of the information it contains is incomplete and tentative. It is hoped, however, that it will provide some practical guidance to those attempting savanna afforestation and, by revealing lacunae in existing knowledge, that it will stimulate research in the study and development of savanna afforestation.

Part I

BACKGROUND

1. THE NATURE AND EXTENT OF SAVANNA

Definition

The term "savanna" was, according to Lanjouw, 1936, originally an Amerindian word used in Haiti and Cuba for treeless plains, and now in popular usage in Latin America. Beard, 1953, states: "Any grassland in tropical America with or without trees or shrubs, natural or man-made, is called savanna today."

The word has been borrowed from Latin America and applied in Africa and other countries to a wide range of tropical and subtropical grasslands, with or without shrub or tree growth, and there is little consistency in the use of the term.

The Multilingual Forestry Terminology Series No. 1 (Ford-Robertson, 1971) contains the following definitions:

> "SAVANNA ... [loan word from Spanish zavana]
> ≈ [a near synonym of] bush veld(t) [S. Africa], tree veldt [Rhodesia]

Essentially lowland, tropical and subtropical grassland, generally with a scattering of trees and/or shrubs. NOTE: If woody growth is absent, termed **grass savanna**; with shrubs and no trees, **shrub savanna**; with shrubs and widely, irregularly scattered trees, **tree savanna**. Cf. SAVANNA WOODLAND, PRAIRIE → DERIVED SAVANNA

"SAVANNA WOODLAND

A more or less open, tropical or subtropical woodland having an undergrowth mainly of grasses, the trees being of moderate height and generally deciduous, or, if evergreen, tending to have small leaves ...

"WOODLAND ...

(2) More particularly, as in the tropics and western USA, plant communities in which trees, often small and characteristically short-boled relative to their depth of crown, are present but form only an open canopy, the intervening areas being occupied by lower vegetation, commonly grass, in contrast to a typical wood.

"FOREST ...

(2) More particularly, a plant community predominantly of trees and other woody vegetation, growing more or less closely together.

"PRAIRIE ...

An extensive tract of level or rolling land that was originally treeless and grass covered. NOTE: (1) Generally characterised by a deep fertile soil. (2) Similar but generally infertile tracts in S. America are termed **llano** north of the Amazon, and **pampa** south of it; in Asia, **steppe**, in S. Africa **high veld(t)** → SAVANNA"

The Terminology does not define the word steppe, except as above under prairie.

The term " savanna " is too comprehensive and vague to be of much use as an ecological unit of classification. Nevertheless it is a concept that conveys a general idea of a particular range of vegetative types of which the characteristic feature is a more or less dense grassy ground layer, in which woody vegetation may or may not be present, and when present is usually irregular.

A feature of much of the savanna under consideration is the annual or periodic burning of the grass layer. This factor is, in many cases, responsible for maintaining the savanna in its present state. Protection from fire, were it possible, would result in an increase in the density of the tree growth, especially in those savanna types in higher rainfall areas which have been derived from high forest by repeated burning of the ground vegetation.

For the purpose of this manual, savanna is

considered as including the full range of *tropical* vegetation types of which grass is a significant characteristic. At one end of the spectrum, closed forest and thickets are excluded, since they shade out all but a few highly specialized species of grass; at the other end desert is excluded, because there is insufficient moisture for grasses to flourish. Between these extremes savanna in the broad sense comprises the various types of savanna woodland, savanna and steppe described in Appendix 1. Inasmuch as these have broadly similar climatic and other ecological conditions and give rise to similar problems of afforestation and development, they can be regarded as a whole. In the following sections, therefore, the term " savanna " is used in the broad sense to include these three plant formations, except where otherwise indicated. Temperate plant communities, including grasslands, in north and south Africa and at high altitudes in the tropics, are excluded.

Extent

The extent of savanna in Africa is shown on the Vegetation map of Africa (see maps, centre inset). This map is at a scale of 1:25 million and does not, therefore, purport to do more than indicate the broad zones of vegetation.

As can be seen from the map the savanna stretches across the continent north and south of the equator in two broad zones. On the north it is bounded by the deserts of the Sahara and northern Sudan, and on the south by the Karroo desert and the montane and temperate grassland of the eastern part of South Africa. In the centre, it is divided into two broad zones by the moist forests of west Africa and Zaire which extend on either side of the equator as far as western Uganda; east of that, i.e. in east Africa, the two zones coalesce. In terms of latitude, the northern zone lies roughly between 5° and 17°N of the equator and the southern zone between 5° and 25°S. There are few countries between the Sahara and South Africa that do not contain some savanna.

In altitude, savanna extends from sea level to about 1 500 metres. In area the savanna is estimated to cover approximately 13 million square kilometres (about 5 million square miles).

The distribution of the savanna is far from static. In many areas the equilibrium between the savanna and its environment is delicate. On the edge of the moist forest zone, extension of the savanna is common owing to clearing and repeated burning, but there are also instances, where burning and clearing have been excluded, of colonization of the savanna by closed moist forest. On balance, however, it is probable that the annual extension of the savanna far exceeds the area of closed forest colonization.

Types

The Yangambi classification of African vegetation types resulted from the deliberations of the international meeting of specialists in phytogeography held at Yangambi in 1956 under the auspices of the Commission for Technical Co-operation in Africa South of the Sahara/Scientific Council for Africa South of the Sahara. It was an advance on anything previously published and was recommended for general adoption. It provided the basis of the Vegetation map reproduced in the centre inset maps of this manual.

In this classification, distinction is made between woodland, savanna and steppe. Woodland is defined in the same way as " Savanna woodland " in the Multilingual Forestry Terminology. The terms " savanna " and " steppe " are explained in the *Explanatory notes* to the *Vegetation map of Africa south of the tropic of Cancer* which was issued by the Association pour l'étude taxonomique de la flore d'Afrique tropicale with Unesco assistance in 1959:

" The adoption of the terms ' savanna ' and ' steppe ' at the Yangambi Meeting and in the present map is a somewhat controversial point. In the sense used here the classification is based on the nature of the herbaceous layer (i.e. savanna or steppe) and then on the density of the woody vegetation. Thus the terms ' savanna ' and ' steppe ' may both be used, with suitable qualifying epithets, for physiognomic types ranging from purely herbaceous vegetation to open woodland.

" The term ' savanna ' is used for vegetation in which perennial mesophytic grasses (e.g. *Hyparrhenia*) at least 80 cm. high, with flat basal and cauline leaves, play an important part; such vegetation is usually burnt annually; although most of the grasses form tussocks isolated from each other, the culms when fully grown form a more or less continuous layer dominating any lower stratum of plants.

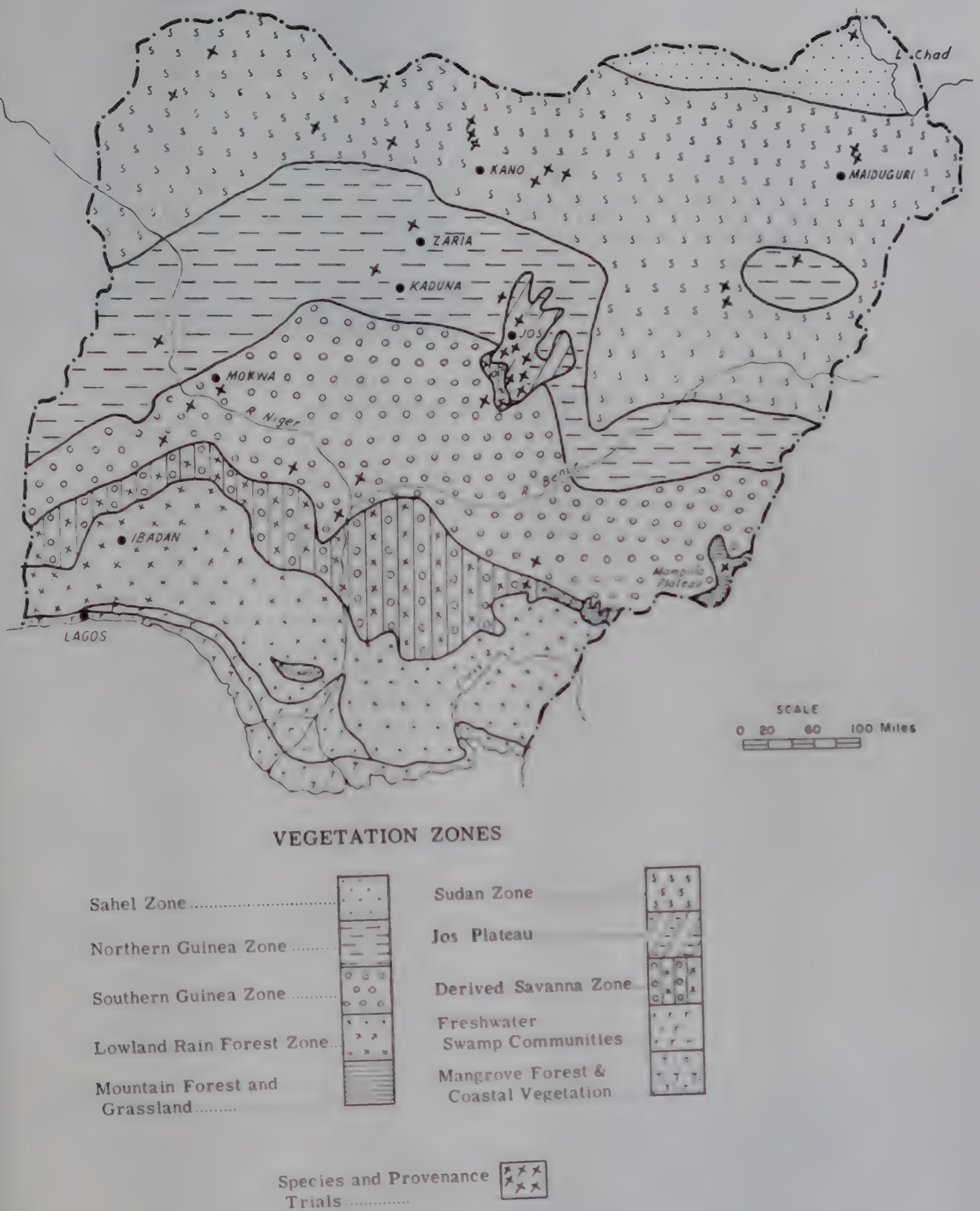


FIGURE 1. Nigerian vegetation zones with principal species and provenance trials in savanna. (*Source:* Savanna Forestry Research Station, Research Paper No. 4. *Courtesy* Director, Federal Department of Forest Research, Nigeria)

"The term 'steppe' is used for vegetation in which annual plants are often abundant between the widely spaced perennial herbs; perennial grasses, when present, have narrow, rolled or folded, mainly basal leaves and are usually less than 80 cm. high; steppe vegetation, at least in the drier areas where it predominates, is far less liable to burning than is savanna.

"... The 'short grass' and 'desert grass' types of E. Africa are included in 'steppe', and the 'high grass' in 'savanna'.

"The grasslands of the tropical mountains and of temperate S. Africa have not been classified as 'savanna' or 'steppe', but are treated separately."

Some ecologists have deprecated the application to African conditions of words first used to describe plant communities in Latin America (savanna) and in Asia and eastern Europe (steppe), and have found inconsistencies in applying the criteria for separating savanna from steppe. Grassland ecologists in east Africa (Pratt, Greenway and Gwynne, 1966), for example, have preferred to use the word "grassland" to cover both the "savanna" and "steppe" of the Yangambi classification. They advocated a clear and arbitrary distinction, based on canopy cover, between woodland (> 20 percent), wooded grassland (2 percent-20 percent) and grassland (< 2 percent). They also distinguished woody growth predominantly of trees (woodland and wooded grassland) from that predominantly of shrubs (bushland and bushed grassland).

Some modification is inevitable when adapting a continental classification, suitable for representation on a single map, to the intricacies of local vegetation. Some authorities distinguish the different types of savanna in west Africa according to the climatic zones in which they occur, e.g. the Guinea, Sudan and Sahelian zones in Nigeria (Figure 1). These zones run roughly parallel to the equator and increase in dryness northward, from the Guinea to the Sahelian. The boundary between the Sudan and Sahelian zones follows approximately the 500-millimetre isohyet, with

FIGURE 2. Indigenous *Acacia seyal* in the Sudan zone savanna of Upper Volta.

(*Courtesy* P.J. Wood)

FIGURE 3. Typical northern Guinea savanna at Afaka, Nigeria. Dominant species are *Isoberlinia doka* and *Uapaca togoensis*.

(*Courtesy* J.K. Jackson)

TABLE 1. — MAIN SAVANNA VEGETATION TYPES

Yangambi classification/ Vegetation map of Africa		Approximate equivalent in	
Formation	Code numbers of vegetation types included (approximate)	Multilingual Forestry Terminology	East African classification
Woodland	15, 16, 22, 23, 24, 25, 27, 28 (part)	Savanna woodland	Woodland or bushland
Wooded savanna	26, 28 (part)	Tree savanna	Wooded grassland
Shrub savanna	28 (part)	Shrub savanna	Bushed grassland
Grass savanna	29 (part)	Grass savanna	Grassland
Wooded steppe	28 (part), 31	Tree savanna	Bushland or bushed grassland
Shrub steppe	28 (part)	Shrub savanna	Bushed grassland
Grass steppe	29 (part), 30, 32, 33	Grass savanna	Grassland

seven to eight dry months (having less than 30 millimetres rainfall). The boundary between the Guinea and Sudan zones follows approximately the 1 000-millimetre isohyet, with five dry months. This differentiation by climatic zones works reasonably well in west Africa but elsewhere in Africa, where the division of climatic regions is much more complex, it is not readily applicable.

The Yangambi classification has two particular advantages: it covers the whole of Africa south of the Sahara and it has been mapped. It is the basis of the Vegetation map (see maps, centre inset) and of the description of the different types of savanna, distinguished in most cases by the characteristic dominant species, which is in Appendix 1.

Table 1 shows an approximate concordance of the terminology of the main plant formations within the savanna, between the Yangambi classification, the Multilingual Forestry Terminology and the East African classification. The vegetation type code numbers refer to those savanna vegetation types distinguished on the Vegetation map and described in Appendix 1. Again, the allocation is only approximate.

2. THE ENVIRONMENTAL CONDITIONS OF SAVANNA

Topography

For such a vast area, 13 million square kilometres (about 5 million square miles), it is possible to do little more than sketch the main features of the topography.

The savanna areas of Africa, for the most part, are of fairly uniform and gentle topography. They consist of a series of undulating plateaux or plains, broken up at relatively infrequent intervals by marked mountain or hill ranges. These plains or plateaux stretch almost across the continent from west to east and from the Sahara in the north virtually to South Africa. In altitude they lie mostly between 300 to 1 500 metres and from west to east they form a vast and very flat arch. The ridge of this arch lies rather toward the east and is marked by a series of mountains and highland massifs which run in a more or less broken chain southward from Ethiopia through Kenya and Tanzania to Malawi and Rhodesia. To the west there are outliers in Sudan (the Imatongs) and Uganda (the Ruwenzoris) and the highlands of eastern Zaire. Further west there are isolated mountain massifs, such as the Jebel Marra of western Sudan, and highlands such as those of the Cameroons and the Fouta Djallon of west Africa. On the whole, however, the predominant feature is the uniform and gentle plain-like nature of the topography; this permits the introduction of mechanical methods in large-scale afforestation projects.

The main river systems draining the savanna regions are the Niger, Volta and Congo in the west, the Nile in the north and the Zambezi in the south. These are fed by numerous streams and there are, in addition, many smaller rivers. Apart from the main rivers, the majority of rivers in the savanna region are of seasonal flow, becoming more or less dry in the dry season. Even the main rivers show marked differences between flood and dry season flow. At the northeast corner of Nigeria is a large depression centred on Lake Chad.

Climate

Climate is the dominant factor determining the type of natural vegetation and the suitability of an area for afforestation; it is also one of the main factors in the choice of species for planting. It involves the complex interaction of a number of meteorological parameters, and space precludes a full discussion here. Reference should be made to the recent and comprehensive account in *Climates of Africa* (Griffiths, 1972), as well as to detailed local or regional accounts (Brown and Cochemé, 1969; Cochemé and Franquin, 1967; Rijks and Owen, 1965; Woodhead, 1968a and 1968b). Discussion here is confined to the most important climatic factors in the savanna region and their variation, which leads to zonation and differentiation between climatic subtypes within the savanna region as a whole.

The seasons

The main seasonal changes in climate in tropical Africa are well summarized by Parry, 1956, as follows:

" Any attempt to subdivide a large region into distinct climatic zones is bound to be very artificial, particularly if the sub-division is done with a view to the selection of species suitable for each zone. Not only does climate grade imperceptibly from one place to another, but its effect on tree growth is modified by other conditions, particularly by soil fertility and by the amount of subsoil moisture available. Moreover, trees vary a great deal in their adaptability, some being restricted within narrow limits, and others growing successfully over a wide range of conditions. None the less, climate is the main factor determining the suitability of an area for tree growth ...

" The climatic regimes of tropical Africa are governed primarily by the biannual swing of the sun and its attendant wind systems across the equator. In very general terms, the wet seasons follow the sun (lagging about a month behind), with the result that throughout most of the equatorial zone there are two wet seasons each year. At the equator itself (or, more accurately, at the rainfall equator which lies about 3 degrees north) the peaks of the two wet seasons occur about a month after each equinox. As one goes north or south from the equator, the two wet seasons move closer together until they coalesce into one wet season. In the northern hemisphere the rains coalesce in the northern summer (July) and in the south they coalesce in the southern summer (February). Owing to the northward shift of the rainfall equator, the single wet season does not occur until about 8 degrees north, whereas in the south it is difficult to detect any marked double season more than 3 or 4 degrees from the equator, though a slight break in the rains may occur in February. The heaviest rains always occur with the northward movement of the sun.

" These general influences are of course much modified by local topography, and by the distance from the sea or lakes. In general, local conditions have a great effect on the total amount of the rainfall, but very little effect on the march of the seasons, though there are a few exceptions to this."

The greater part of the savanna region lies more than 5° from the rainfall equator. Rain is concentrated in a single rainy season, alternating with a dry season in which little or no rain falls for several months on end. The sharp distinction between the dry and rainy seasons in the savanna is perhaps its most characteristic climatic feature.

Temperature

The savanna region lies almost entirely within the tropics and below 1 500 metres. Temperatures are consistently high and nowhere is it considered that temperatures occur low enough to limit vegetative growth. It is possible that exceptionally high day temperatures may temporarily inhibit growth in a few places, but such localities occur mainly on the margins of the desert, where lack of water is a limiting factor anyway. The only circumstance in which high day temperatures might become limiting is in irrigated plantations in very hot places. A contrasting situation occurs during periods of extensive cloud cover during the rains. Daytime insolation, and therefore photosynthesis, is reduced, while reduced net radiation from the earth at night results in higher night temperatures and therefore increased respiration rates. The " hot nights " theory — that, in extreme cases, the balance between photosynthesis and respiration may be altered sufficiently to reduce growth — has been put forward as an explanation for the fact that most of the exceptionally high yielding plantations recorded occur in the highland, rather than the lowland, tropics. As yet, there is little quantitative evidence to confirm the theory. In general, the direct effect of temperature is very seldom limiting in the savanna and temperature is therefore of little importance in climatic zoning of the savanna. On the other hand it is one factor contributing to evapotranspiration, which is often of vital importance and is discussed below.

Rainfall

Mean annual rainfall is shown on map 3 of the centre inset maps. Comparison between this and the Vegetation map shows that there is a broad similarity between mean annual rainfall and vegetation type. The savanna occurs in the zones between about 1 500 millimetres rainfall (forest-savanna mosaic) and 200 millimetres (subdesert). The general pattern is of rainfall decreasing steadily from the high rainfall areas of west Africa and Zaire outward to the Sahara and the subdesert areas of northeast and southern Africa. This pattern is clearest in the western and central portions of the northern hemisphere, but is considerably distorted in eastern Africa by the local effects of mountains in reducing temperature and increasing precipitation.

An important feature of rainfall in the African savanna is the great variation that may occur from year to year. An extreme example quoted (Brown and Cochemé, 1969) is Makindu in Kenya which has experienced annual rainfall as low as 67 millimetres and as high as 1 964 millimetres. Where rainfall records exist over a period sufficient to warrant the preparation of rainfall reliability tables and maps, their use is to be preferred to those of mean annual rainfall in assessing the suitability of an area for forest

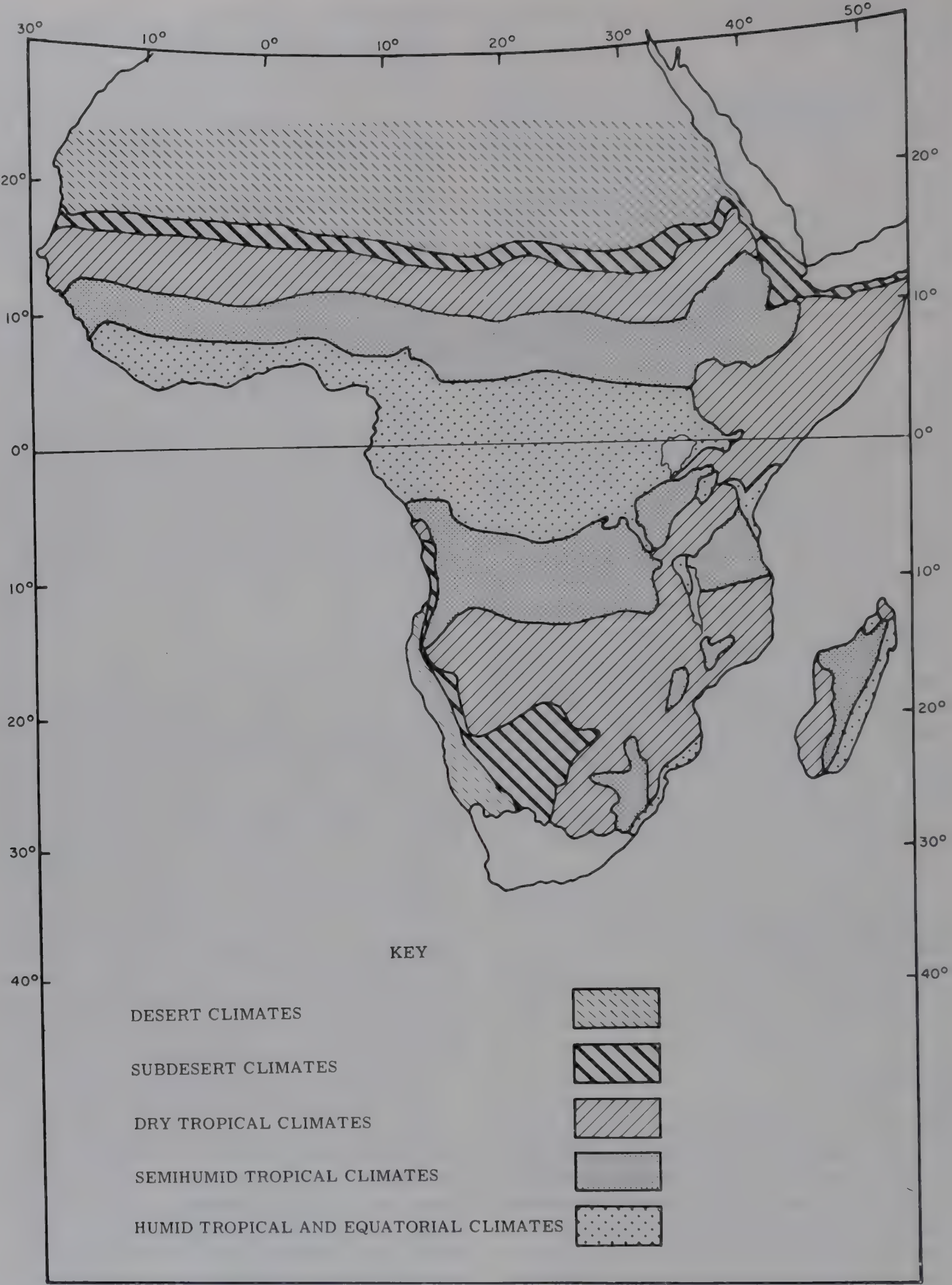


FIGURE 4. Climatic types of Africa.

(After Aubréville)

or agricultural crops. Rainfall reliability maps indicate the minimum rainfall which can be expected at a given probability (e.g. nine years out of ten: Glover, Robinson and Henderson, 1954).

The seasonal distribution of rainfall is often more important than the annual total. The savanna typically occurs in areas of single peak rainfall and a distinct dry season of varying length. In the northern hemisphere the peak of the rains occurs in June/August, in the southern in December/February, i.e. when the sun is near its zenith. This pattern of distribution is sometimes called "summer rainfall," although the range in temperature between the warm and cool seasons may be insufficient to distinguish between "summer" and "winter." The term is useful, however, in emphasizing that the savanna has a very different rainfall pattern from that of the Mediterranean climatic type, in which the bulk of the rain falls in the cold season. Winter rainfall species such as *Pinus radiata* and *P. pinaster* have usually performed disappointingly in the tropics, even at altitudes higher than that of the savanna.

As a general rule, the length of the dry season increases as the total rainfall decreases. In the wettest savanna zone (forest-savanna mosaic) there are about three "dry" months with less than 30 millimetres of rain; in the driest (subdesert), nine to ten months. Considerable variation occurs locally, however; in Nigeria, Kaduna has a slightly higher total rainfall than Ilorin, but a longer dry season (five dry months compared to three).

Evapotranspiration and water balance

In much of the savanna availability of soil moisture is the limiting factor for plant growth. Information on the seasonal inflow of moisture into the soil from rainfall is of limited value without information on the corresponding moisture losses due to run-off, subsoil percolation and evapotranspiration. The concept of estimating seasonal changes in the water balance, that is the soil moisture balance resulting from monthly rainfall, monthly potential evapotranspiration (E_t) and the moisture storage capacity of the soil, was developed by Thornthwaite, 1948. It represented a valuable advance in the science of describing, comparing and classifying climate from an ecological viewpoint.

In Africa the use of the Thornthwaite system of expressing climate in terms of the water balance has been widely adopted, but his formula for calculating potential evapotranspiration has been found less appropriate for the tropics than for North America and has been largely superseded by that of Penman, 1948.

Examples of diagrammatic representation of the water balance for some representative savanna stations are shown in Appendix 2. They indicate that total annual potential evapotranspiration often exceeds total rainfall, even in the wettest parts of the savanna, and may be five to ten times as much in the subdesert. Furthermore, both seasonal and geographical distribution of rainfall is in approximately inverse relation to potential evapotranspiration; a low rainfall month has a higher potential evapotranspiration rate than a high rainfall month, and a low rainfall area has a higher potential evapotranspiration than an area of high rainfall.

Comprehensive studies by Birot and Galabert, 1972, in a plantation of *Eucalyptus crebra* near Ouagadougou in Niger, which has a dry tropical climate with 850 millimetres total rainfall and a dry season of five to six months, showed that the seasonal pattern of actual evapotranspiration (E_a) in these conditions is related more to rainfall than to the potential evapotranspiration (E_t). E_a is at its minimum for much of the dry season, when E_t is at its maximum, simply because the reserves of moisture in the soil resulting from the wet season have become exhausted. During the rainy season, when E_a was at its maximum, it was calculated to amount to 4.1 millimetres per day, or about two thirds of the estimated 6.5 millimetres E_t. Of this, it was estimated that approximately half was accounted for by transpiration of the crop and half by physical evaporation from the soil surface.

Climatic classification

The water balance method offers a rational means of subdividing the savanna into climatic subtypes. Several regional maps have been produced (Brown and Cochemé, 1969; Cochemé and Franquin, 1967; Woodhead, 1969), but no map of this type exists for the whole of the savanna. The method requires the measurement of several climatic parameters by instruments which are commonly available only at the bigger meteorological stations. For this reason, simpler methods of classifying climate, based on rainfall

TABLE 2. — TYPES OF CLIMATE IN TROPICAL AFRICA

Type	1 Desert	2 Subdesert	3 Dry tropical	4 Semihumid tropical	5 Humid tropical and equatorial
Annual rainfall	<200 mm	200-400 mm	Usually 400-1 000 mm	Usually 1 000-1 500 mm. Sometimes as low as 800 mm	Usually >1 500 mm. Lower in east Africa
Number of rainfall peaks	1	1	1	1	Usually 2
Number of dry months [1]	10-12	8-11	Usually 6-7 Sometimes 5 or 8	4-5 Sometimes 6	0-3
Number of very rainy months [2]	0	0-2	Usually 2-5 Often 3-4	Usually 5-6	Usually 7-9
Mean annual temperature in °C (varying with altitude)	28°-32°	26°-32°	25°-31°	24°-28° (20°-22° in Saba province, Zaire)	23°-27°
Mean annual saturation deficit [3] (derived from monthly means)	Extreme	Very high to extreme	High to extreme Occasionally low (Togo) or average (south Madagascar)	Average or high Sometimes low	Very low or low Occasionally average

[1] A dry month is here arbitrarily defined as a month with 30 millimetres or less rainfall.
[2] A very rainy month is here arbitrarily defined as a month with over 100 millimetres rainfall.
[3] Saturation deficit (SD) is defined as the difference between the actual vapour pressure (AVP) in the air at the time of measurement and the saturation vapour pressure (SVP) at the same temperature (i.e. the maximum vapour pressure possible in air at the same temperature which will remain in equilibrium with an open water surface). Vapour pressure is expressed in terms of the height of a column of mercury (in millimetres) with which it remains in equilibrium, or sometimes in millibars. Aubréville, 1949, defines the above categories of mean annual SD as follows:

Very low	< 3 mm	High	7-10 mm
Low	3-5 mm	Very high	10-15 mm
Average	5-7 mm	Extreme	> 15 mm

It may be noted that relative saturation deficit percent (RSD), which is complementary to the relative humidity (RH), and is given by the formula $RSD = \frac{SVP - AVP}{SVP} \times 100$' increases with rising temperature.

and temperature alone, have been most used in the past, e.g. the methods of Gaussen, 1954; Emberger, 1952; Walter and Lieth, 1967; Holdridge, 1967; and Unesco/FAO, 1963.

For the present manual, the climatic map shown in Figure 4 and based on the work of Aubréville, 1949, provides a relatively simple synthesis of the main factors. Aubréville recognized some 53 different climatic units in tropical Africa which he grouped into five main climatic types. These are, in order of increasing humidity:

1. Desert climates (4 units)
2. Subdesert climates (3 units)
3. Dry tropical climates (23 units)
4. Semihumid tropical climates (14 units)
5. Humid tropical and equatorial climates (9 units).

The principal characteristics of these main types are shown in Table 2.

Savanna woodland and wooded savanna occupy most of the semihumid tropical climate, while wooded steppe is characteristic of the dry tropical climate. The other climates are of less importance as a habitat for savanna vegetation types. The humid tropical and equatorial climates typically carry tropical high forest, but have limited areas of forest-savanna mosaic and

derived savanna. The subdesert carries mainly grass or succulent steppe, but its area is restricted.

Soil

As in the case of climate, there is a great variety of soils in the savanna region. The practical forester is more concerned with the properties and local variation of soils within a particular afforestation project than with the past evolution of the soil profile or with broad systems of regional or continental soil classification. For present purposes, therefore, the main emphasis has been placed on the chief soil characteristics which are of importance for savanna afforestation, but references are given to the more important soil classifications that have been made, both on a continental scale and for individual countries.

Properties

The main properties that require discussion are depth, structure and permeability, fertility and acidity or alkalinity. Of these depth and permeability, because of their influence on available water, are the most important factors for tree planting under the relatively arid conditions of the savanna.

Depth

Soil depth, by which is meant rooting depth, is apt to be extremely variable over short distances throughout the savanna region. The general pattern is that colluvial and alluvial soils are usually deep, but residual soils are highly variable, depending on the degree of slope, the length and intensity of weathering, and biotic influences such as cultivation and grazing, which affect erosion and the formation of plough pans. In the topographical sequences of soils which occur over much of east and central Africa, Angola and west Africa, the soils of the ridges and upper slopes are often shallow and those of the midslopes and valleys moderately deep to deep. But in the valleys rooting depth may be limited by a high seasonal water table. The midslope soils normally have the greatest rooting depth and are the best for tree growth.

The depth of soils in the savanna region is often limited by a layer of ironstone or lateritic gravel. This layer may be discontinuous, e.g. in nodular form, or, in its most advanced state, more or less continuous and may be anything from 5 to 60 centimetres below the surface. Other common names for it are "pea ironstone," "murram," "pseudolaterite" and, in its most advanced and continuous form, indurated "plinthite" or "carapace latérique." This most indurated type can have a strong inhibiting effect on the penetration of tree roots, and in its more advanced stages may render a site unsuitable for planting. In some areas extensive outcrops occur on the surface. On the other hand, roots of some tree species are able to penetrate the less compact forms of plinthite, and to draw water from beneath.

Structure and permeability

Not a great deal of information is available regarding the structure and permeability of savanna soils. The black and grey clay soils (vertisols) of central and eastern Sudan, and of east Africa, normally become more or less completely impervious when wet and crack deeply when dry. In consequence, little of the rainfall penetrates during the wet season and in the dry season these soils dry out to a considerable depth. They are, therefore, extremely difficult to afforest without irrigation.

When, however, irrigation is possible these soils become relatively easy to afforest. Recent species trials in the irrigated Khartoum greenbelt have shown that quite a wide range of species grow well on these soils in the younger stages. Their future development will be watched with interest.

Similar conditions exist more extensively in the calcareous clay soils of the east African plains, but irrigation is usually not available here. It has been suggested that subsoiling might be helpful in these conditions, in order to improve the structure and permeability (Bigg, 1961).

One feature of these deep cracking clays is the uniform nature of the deep surface layer. This is due to a natural process of churning in which the surface soil is washed down the cracks at the beginning of the rains, before the deeper soil has had time to swell and close them. It has been said that such soils plough and cultivate themselves. The cracks have a beneficial effect in assisting root aeration in an otherwise impermeable soil but, if cracking is very severe, physical damage to the roots may result, making establishment difficult.

At the other extreme, the deep coarse sands have high permeability and a low capacity for water retention. An important feature of these soils may be the depth to which the water table falls in the dry season and, in particular, whether the capillary fringe, rising about a metre and a half above the water table itself, drops below the reach of the roots.

Fertility

For many species, fertility is of less importance for tree planting than soil depth and available water, and it is relatively rarely a limiting factor. It may, however, be important during the first few years after planting, when the absence of certain trace elements, notably boron, may be critical.

Over much of the savanna region the soils are of low fertility, in some cases because of the inherent poverty of the parent material, and in others because of the temporary exhaustion of the soil by previous cropping.

Organic matter. There is little deposit or accumulation of litter under savanna conditions; estimates of annual litter deposition vary from a few kilogrammes to a few hundred kilogrammes per hectare, compared with several thousand kilogrammes per hectare under rain forest. Moreover, the annual fires to which most of the savanna is subject soon destroy any accumulation of litter. In consequence, savanna soils are usually deficient in organic matter and quickly lose what little they have under cultivation.

Nitrogen. In general savanna soils have a low nitrogen content. Total N values have been recorded for soils in east, central and west Africa, Sudan, Angola and Rhodesia. Despite wide variations of vegetation, local climate and soil, the values in the upper horizon are commonly between 0.02 and 0.10 percent. Higher values, e.g. from 0.15 to 0.30 percent, are relatively rare. The higher N values are usually found in the heavier soils of the semihumid savanna woodland and in soils with a high organic-matter content.

The annual return to the soil of nitrogen from organic residues of trees and grass is said to be higher in savanna woodland soils than in grass savanna. Studies in the derived savanna of Zaire and west Africa have shown the total N return of grass and its roots to be 30-135 kilogrammes/hectare annually. The upper figure approaches that found in the early years of secondary succession under forest fallow. In the more arid savanna areas, however, a return of less than 34 kilogrammes/hectare per year is more usual.

Phosphorus. With local exceptions, savanna soils generally show a widespread deficiency of total and available phosphorus. Studies in west Africa show that the value of the total P in the upper horizons ranges from about 61 to 229 ppm (parts per million). In other parts of Africa lower figures than these have been recorded. The following are some examples:

Derived savanna woodland of Zaire	35-39 ppm
Miombo woodland of Angola (1 000 millimetres rainfall)	50 ppm
Colophospermum mopane woodland (250-750 millimetres rainfall)	20 ppm

Data from east Africa and Zambia also confirm the deficiency in phosphorus.

The annual return of phosphorus to savanna soils is thought to be appreciable. For instance, a return of 5.8-10.3 ppm annually, equivalent to 68-135 kilogrammes/hectare of single superphosphate, has been recorded for tall grass savanna woodland in Ghana. Nevertheless, the proportion of phosphorus actually retained is probably small because of the effects of dry season winds, fires and early rains, especially on slopes. However, if grass and thicket fallow are protected from fire and other disturbances for a period of five to ten years a measurable return of phosphorus to the soil is believed to accrue.

Potassium. Savanna soils are generally richer in total and exchangeable potassium than forest soils. In Ghana, Senegal and Nigeria, the soils are reported mostly to contain enough potassium for adequate plant growth, but some of the heavily leached and sandy soils are deficient. In the derived savanna woodland of Zaire, in Angola, Zambia, Rhodesia and southeast Tanzania, low values for exchangeable potassium are reported.

Calcium. Calcium deficiency is not often a limiting factor in savanna soils but, where it occurs, it may be important for teak planting, as the growth of teak appears to be sensitive to calcium deficiency.

On the other hand, excess calcium can sometimes be a limiting factor. Trials in eastern Sudan showed that, among the eucalypts, *E. microtheca* and *E. gomphocephala* were tolerant of high calcium content in the soil; *E. tereticornis* gave inconclusive indications, dead and healthy trees being found in the same trial plots; but repeated attempts to grow *E. citriodora* failed, chlorosis developing very shortly after planting out in the calcareous clay.

Trace elements. Little is known of the influence of trace element deficiencies in savanna soils. Recent experience in Zambia (Cooling and Jones, 1970) and in northern Nigeria has established that various species of *Eucalyptus* are susceptible to boron deficiency, and that application of boron reduces or eliminates casualties due to lack of this element. On the other hand, on sandy soils of low buffering capacity, boron toxicity can easily be induced if minimal doses are exceeded.

Acidity — alkalinity. Acidity or alkalinity may be of importance because some of the species likely to be used in savanna planting are sensitive in this respect and will only grow within a limited range. Very little is known at present about the range of tolerance of many of the species used but, for example, most pines do not normally do well unless the soils are acid, preferably in the range pH 4-6, and *Azadirachta indica* in Nigeria has been found to do best on less acid soils, of pH not less than 6.

The majority of savanna soils are slightly acid, unless derived from calcareous rock. The following are some pH values for various savanna soils:

Northern Nigeria, sandy soils near Zaria	pH 5-6
Northern Nigeria, others	pH 6-7
Cameroon	pH 6-7.4
Sudan, Kordofan and Darfur acid sands	pH 5-6
Sudan, alkaline sands and clays	pH 7-8.5
Sudan, humid southern savanna	pH 6-7
Sudan, Gezira	pH 9.4
Congo	pH 5-6
East Africa, loamy sands with laterite horizon	pH 5-7
East Africa, sandy clay loams	pH 4.5-6
East Africa, black clays (black cotton soils)	pH 7-8.5
Zambia and Rhodesia	pH 5-6

The pH values may vary at different horizons in the profile, the trend depending on the acidity of the parent material and upon the amount of leaf litter under forest.

Erosion. Erosion can be a serious problem on many savanna soils. There is, however, a grave lack of reliable information and data on (*a*) the loss from various soils under differing conditions and (*b*) the " loss tolerance " of different soils. Regarding the former, preplanting surveys (e.g. that preceding the United Nations Development Programme Kordofan project) frequently mention erosion and may even subjectively quantify it in such terms as " negligible," " moderate," " very severe," etc., but such assessments are generally based on personal observations and opinions; reliable quantitative measurements are conspicuously lacking.

A map compiled by Fournier, 1962, shows a broad zonation into four categories of erosion risk based on climate and topography, but does not record data of erosion actually measured. Most of the savanna falls into one or other of the two middle categories (i.e. losses from erosion estimated at between 200 and 2 000 tons/square kilometre/year).

When reliable quantitative data on erosion losses have been collected, it is important to interpret them in terms of the soil " loss tolerance " of the various soils. Soils that have a shallow fertile surface layer over an infertile subsoil can stand little erosion without severe loss in fertility. On the other hand a deep dune sand, in which nutrients have been washed down to lower levels, can stand a considerable amount of erosion with little or no loss in productivity. Indeed, there may be a gain where some loss of surface soil enables young plants and trees to reach the nutrients more readily and return them to the surface through leaf litter. The whole subject of erosion in savanna soils deserves more systematic quantitative investigation.

Soil exhaustion. Continuous agricultural cropping has been found to exhaust the nutrients in soils to a greater extent than certain forms of tree cropping. For instance, in the Goz sands of eastern Kordofan in Sudan, a comparison between soils of adjacent plots, one of which had been continuously cultivated with agricultural crops for 30 years and the other under *Acacia senegal* for the same period, showed the following differences:

	Agricultural cultivation	*Acacia senegal*
pH	5.2	6.3
Organic nitrogen (ppm)	65.0	110.0

We are, however, almost completely ignorant of the effects on soil fertility of pure plantations of fast growing eucalypts or pines, managed on short rotations. Such crops often give dramatically higher production in the first rotation than the natural forest they replace, but we do not know whether this is at the expense of soil nutrient reserves and, if so, whether remedial action is possible to maintain site productivity by the addition of appropriate fertilizers. Maintenance of the physical conditions of the site and of water supplies in the rooting zone under such crops is no less important. There may also be a " specific replant problem " such as is found in fruit orchards, where failure of second rotation crops of the same species is experienced. This is also happening with second rotation crops of *Pinus radiata* in New Zealand, and may also occur with exotic species planted in savanna. These are subjects demanding urgent investigation and research.

Classifications and types

On a continental basis there have been four attempts to classify soils; those of Marbut in 1923 (Shantz and Marbut, 1923), Schokalskaja, 1953, D'Hoore, 1964, and of the current FAO/Unesco project for the production of a Soil map of the world, on which 22 major soil groups are shown for Africa. The nomenclature and definitions of the soil units used in the world soil map attempt to synthesize experience from pedologists all over the world, in order to achieve the widest possible application (FAO, 1968, 1970b).

For the present manual, the Soils map from the *Oxford regional economic atlas: Africa*, 1965, has been reproduced (see maps, centre inset). This is a simplified version of D'Hoore's 1964 map. It is useful in showing the main soil types which occur in the savanna, which are described briefly in Appendix 3. But at a scale of 1:25 million, at which 1 square millimetre represents 62 500 hectares, it can clearly give no guide to local distribution of soils. Any broad scale classification has little application to savanna afforestation, as the soil types must inevitably be very wide, whereas afforestation will be concerned with relatively small areas and with very local changes of soil. The latter may be too small for distinction in a continental classification but can be appreciable locally and of great significance in afforestation. For practical purposes, therefore, local classifications are of more importance for afforestation.

Among the local classifications which require mention are those of Worrall, 1961, for Sudan; Scott, 1961, for east Africa; Vine, 1953, for Nigeria, with Klinkenberg and Higgins, 1968, for northern Nigeria; Dabin, Fauck and Pias, 1967, for west Africa; Trapnell, Martin and Allan, 1948, for Zambia; and Ellis, 1951, for Rhodesia. These should be consulted for local information on soils, but space does not allow for their further consideration here.

An important feature of African soils is the frequency of recurrent changes in soil (and vegetation) characteristics associated with recurrent changes in topography. This is common in many parts of the savanna, where climate is uniform over large areas, topography is gently undulating, and the effect of geological variation has been largely eliminated by the great age of the soil profile and the deep weathering of the underlying rock. In these conditions, position on the slope is the most important factor determining soil characteristics at any point. For example, the soil may vary from a sandy ferruginous tropical soil (or red earth) at the tops of the broad ridges to a black cracking clay in the depressions, with intermediate types in between. The pattern of variation is repeated endlessly in conformity with the topography, so that two soil profiles 100 kilometres apart may be identical, while two 100 metres apart are entirely different. This pattern of variation has been variously described by the terms " topographical sequence," " soil association " or " soil complex " and (in east Africa) " soil catena." It may be

important in afforestation since it complicates management. Either a variation in growth and yield must be accepted, or more than one species may have to be planted to cover the range of topographical variation, or the most unsuitable parts of the sequence may have to be left unplanted. This feature of the savanna makes efficient soil survey an essential prerequisite for successful large-scale planting. For example, a recent report from Nigeria (FAO, 1970a) indicates that in a survey of nine savanna forest reserves covering 99 000 hectares, 35 percent of the area was classed as unsuitable for afforestation, 48 percent as moderately suitable and only 17 percent as suitable.

Biotic and economic factors

Fauna

Wildlife may have a significant effect on tree crops in the savanna, both natural and planted, especially when local concentrations of population occur. The larger gregarious herbivores, elephant and buffalo, sometimes do serious damage. Few trees are big enough to be immune from elephant damage and trees are sometimes pushed over for amusement, as well as for food. Since elephants often follow the same seasonal migration routes year after year, damage to forest plantations may be reduced by siting them well away from these routes. Young trees are sometimes browsed by the smaller ruminants, bush buck and duiker, and baboons are capable of serious damage through breaking of branches in saplings and young poles.

One of the most characteristic features of savanna is the abundance of termites and termite mounds. Termites feed on the roots of some species of newly planted trees, but there is great variation in specific resistance of the host. Special insecticidal treatment is essential for most eucalypts, if catastrophic casualties from termites are to be avoided, whereas *Cassia siamea* and most of the pines are usually immune. The mounds constitute a serious impediment to mechanized site preparation. On the other hand, the increased proportion of clay and calcium in the soil in and around termite mounds may provide a local improvement in soil quality, especially in a predominantly sandy soil.

Human population

The total population of Africa is estimated to be about 354 million (United Nations. Statistical Office, 1972). Out of this it is reckoned that about 140 million live in the savanna region. On the estimated area of around 13 million square kilometres for the region, the average density of population in the savanna is about 11 persons per square kilometre (or 28 persons per square mile) but, of course, locally there are large variations from this mean figure.

Recent census figures indicate that the population in many of the countries included in the savanna region is increasing at a rate of between 1 and 2 percent per year. Although over wide areas of the savanna there is as yet no acute pressure on the land, this rising trend of population must, in time, create very considerable pressures in the more favourable localities; already this has occurred in some areas, for example in parts of northern Nigeria and Ghana. The future pattern must inevitably be one of continuing and increasing clearing of the woodland around the main centres of population.

Fire

In the moister parts of the savanna, wherever grass accumulates, fire is frequent, often annual. Though occasional fires may be started by lightning, the overwhelming majority is man-made and may therefore be considered among the biotic factors. Fire is such an inescapable feature of much of the savanna region, especially in the semihumid tropical climate and in the derived savanna, that some ecologists consider the whole vegetation type to be a fire climax. Be that as it may, it is certain that adequate provision for fire control will have to be an essential part of any afforestation project which takes place in the moister parts of the savanna (see Appendix 7). In the subdesert and the drier parts of the wooded steppe, where grass becomes discontinuous and short in stature, fire is no longer a dominant factor, but these areas are usually too dry for economic afforestation.

Economic activities

The people of the savanna region are mostly dependent on agriculture and stock raising for their livelihood. As a rough estimate it is

hazarded that three out of four are engaged in or dependent on these activities. Both are predominantly subsistence activities, the general pattern being one of small scattered holdings of family cultivation or family herds. Plantation agriculture or commercial ranching are relatively scarce but in a few localities there has been appreciable development of plantation crops, notably sisal in Tanzania and Kenya and cotton (under irrigation) in Sudan.

The normal system of peasant cultivation consists of cropping followed by bush fallow; permanent cultivation is rare. With increasing population, the fallow period in many areas is getting shorter and the vegetation is thus slowly, and in some cases quite quickly, being degraded. In addition to the usual food crops of millet, guinea corn, sesame, etc., some cash crops are commonly grown, notably cotton, groundnuts, tobacco, etc. Domestic livestock comprises cattle, sheep and goats.

As would be expected from the climatic conditions, arable agriculture is mainly concentrated in the drier parts of the semihumid tropical climate and the wetter parts of the dry tropical climate, while stock raising becomes dominant in the drier parts of the dry tropical climate and in the subdesert. In the more humid climates the presence of tsetse fly commonly precludes agriculture. Tsetse fly is, in fact, one of the main agencies of forest preservation in these areas. Over much of the stock-raising zone, stock is regarded as a form of wealth and there is little inclination on the part of cattle owners to cull or sell off the natural increase. In consequence, there is a common trend toward building up the maximum herds that the water supplies can support, and the vegetation in these areas is thus all too often subject to considerable destruction or degradation by domestic livestock. In Sudan, for instance, grazing in the *Acacia senegal* savanna in Kordofan is not a widespread problem either to trees or soils because there is insufficient water to support large herds. In the south, however, where there are numerous boreholes and also natural pools which fill in the rainy season, the herds are much larger and the destruction is not only of vegetation but also of soils. Particularly on the clay plains, the scuffling and subsequent removal by wind erosion of the shallow top soil has exposed large areas of the hard clay pan. The rate of increase in this exposure has not been measured, though this could readily be done from successive aerial photographs. The whole process of deterioration of vegetation and soil on the clay needs further study.

In a very few areas in the savanna region, notably the copperbelt of Zambia and southern Zaire, there is a certain amount of mining activity, but it is only really important in the copperbelt. Here, in addition to requiring large quantities of forest produce, mining also provides well-paid employment and creates a social group less dependent on agriculture and stock raising and with higher standards of living.

Apart from mining, industrial development in the savanna region is very small. Here and there bricks or lime are burnt, and near the larger lakes and rivers fish drying may be of local importance. Another industrial activity of interest from the forestry point of view is tobacco curing but this is usually scattered and on a small scale. There is a certain amount of industrial development in the north of Nigeria, particularly textile manufacture, cigarette manufacture, groundnut crushing and tanning, all of which are based on the agricultural and forest products of the region.

The collection of beeswax and honey in savanna areas is a small local industry in most countries, though in some, e.g. Tanzania, it attains considerable size and contributes materially to the export trade of the country.

Overall, the general picture of the savanna region is one of a low level of economic development. Per caput incomes are small and the standard of living low. The former are commonly less than U.S.$100 a year and the latter is limited more or less to basic necessities.

With regard to the future, it is difficult to foresee any great changes in the pattern of economic activities, unless there are important new discoveries of minerals or oil. Lacking these, any great degree of industrial development is unlikely and the main economic activities in the savanna must continue to be agricultural and pastoral. There will, of course, be improvements in techniques and practices; but again, it seems unlikely that there will be any revolutionary changes, except possibly in a few areas where irrigation is practicable. If these predictions are correct, per caput incomes in a great part of the savanna region are not likely to increase rapidly or reach a very high level in the foreseeable future.

3. THE ROLES OF FORESTRY IN THE DEVELOPMENT OF SAVANNA

As indicated in the preceding chapters, the two principal basic factors of social and economic development which forestry must take into account in the savanna region are:

(*a*) increasing population, both human and livestock;
(*b*) a rising standard of living.

The increase in population is likely to be fairly rapid. Estimates of 1 to 2 percent per year have been made which will mean a doubling of the population in about 35 to 65 years, but it is possible that even a small rise in the standard of living will result in higher rates of population increase. At the same time, having regard to the extremely low level which constitutes the starting point for the standard of living and of individual wealth, even a small rise in actual individual income will be significant in terms of better nutrition and welfare; but this trend will be counteracted to a greater or lesser extent by the consequent increase in rate of population growth.

The combined effect of these interacting factors will be to generate increasing demands for forest produce of all kinds and increasing pressure on the land; the latter will in turn give rise to increasing dangers of degradation and denudation of savanna sites and of overexposure of the soil, because of more widespread and frequent cultivation, with shorter bush fallow periods and more overgrazing. This could lead to deterioration of the water-regulating capacity of catchment areas and to loss of fertility of the soil.

The role of forestry in the savanna region is, therefore, to meet these growing demands for forest produce as they arise and to provide the necessary protection for catchments and soils; another role will be to provide amenities for the people near the larger towns. The elements of these roles are discussed in more detail in the following sections.

Requirements for forest produce

Consumption surveys and forecasts of future needs

The basic requirement for fulfilling the production role of forestry is a clear picture of the anticipated future needs for forest produce. This must include not only the quantities of the various kinds of forest produce that are likely to be required but also the qualities or types of wood needed. Without such a picture of future needs, production planning is little better than guess-work and may result in important failures to produce what is needed, or in expensive errors. This applies the more so in the case of long rotation crops such as timber which require long-term advance planning.

One of the main difficulties confronting the planner of production forestry in the savanna region is the lack of reliable data on the demand for forest produce, not only in the future but also at present. One of the difficulties in relation to plantation produce is that in early surveys one is often dealing with an unpriced product not presently available in the market. For a few countries, notably Kenya, Uganda, Tanzania and Sudan, systematic country-wide surveys of current consumption and forecasts of future needs have been made (FAO, 1967), and in a number of other countries, e.g. northern Nigeria (Thulin, 1966), smaller local or *ad hoc* surveys or forecasts have been made. But for much of the region there is very little information on the present pattern of consumption and only very vague and speculative forecasts of future needs. The fact that creating forest resources in the savanna region will normally be an expensive undertaking and that few of the countries are overblessed with financial resources for development makes it all the more necessary that plans for the development of production forestry

FIGURE 5. The continent of Africa.

(*Source:* FAO. *Timber trends and prospects in Africa,* 1967)

should be soundly based. A fundamental requirement for this is as realistic an appraisal as possible of the future production targets to be met.

All countries or forest authorities which have not yet made a careful assessment of their consumption and their expected future requirements are therefore urged to do so. In this respect it should be recognized that such surveys and forecasts are not " once for all " exercises but should be repeated at intervals. Only in that way can reliable indications of trends in patterns of use be established and production plans be kept up to date and adjusted to meet the changing needs that will surely arise. Meanwhile the first survey provides the essential basic data from which to plan initially.

FIGURE 6. Stacked firewood from second-growth coppice crop of *Eucalyptus microtheca* irrigated plots in Sudan.

(*Courtesy* M.A. Waheed Khan)

PRESENT REQUIREMENTS

As a basis for estimating present consumption of wood, the following figures have been extracted (and rounded) from a previous survey of timber trends and prospects in Africa (FAO, 1967). The figures are for 23 countries in western Africa and 16 countries in eastern Africa, and refer to estimated annual consumption 1959-61.

TABLE 3. — ANNUAL CONSUMPTION OF WOOD PRODUCTS IN EASTERN AND WESTERN AFRICA 1959-61

Type of product	Total consumption	Consumption per caput	
		Average	Range for individual countries
	Thousand cubic metres	*Cubic metres*	
Fuelwood	170 000	0.90	0.16 - 1.48
Roundwood (poles, posts, pit props)	9 700	0.05	0.02 - 0.20
Sawnwood (sawn output)	1 900	0.01	0.0003-0.06
Sawnwood (roundwood input)	3 800	0.02	0.0006-0.12

Fuelwood

Fuel, either in the form of firewood or charcoal, is undoubtedly the forest product for which there is the greatest demand at present in the savanna zone, and which is most important in the lives of the people. The greater part of it is used for domestic purposes. In addition, a certain amount of wood fuel is also used institutionally, e.g. by hospitals and schools, and industrially for such purposes as brick burning, tobacco curing, fish drying, blacksmiths' shops and mining.

In general, it is difficult to get accurate figures for quantity, as much of the fuel is cut from land for which no records are available. Moreover, figures for consumption supplied by domestic consumers are commonly far from reliable.

The countries which contributed to the survey summarized in Table 3 contain substantial areas which are not savanna. A study of the figures for per caput consumption in different countries shows that those countries with large areas of high forest generally have higher per caput figures and that, on the average, the countries with mainly savanna forests have per caput consumptions below the general mean of 1.00 cubic metres.

Assuming 0.6 cubic metres per year as the per caput consumption from savanna areas and the population as about 100 million, one arrives at a total consumption of the order of 60 million cubic metres of firewood a year. This figure is probably a very conservative one. If institutional and industrial needs are added, at an assumed 10 percent of domestic consumption, a grand total may be hazarded of the order of 66 million cubic metres a year as a minimum.

Roundwood (poles, posts, etc.)

Next in importance to fuel are poles. The great majority of houses in the savanna region are round or square huts, commonly constructed of a framework of poles and withies daubed with mud and with a thatched roof carried on pole rafters. In addition there is some consumption for institutional purposes such as schools, dispensaries and markets, and for industrial use such as scaffolding, telephone and power transmission poles and as supports for concrete shuttering or in mining. Poles are also used in some areas for fencing for livestock.

As in the case of fuel, figures of consumption are scarce and, for similar reasons, none too reliable. From the figures in Table 3, an annual domestic consumption of at least 0.05 cubic metres per head, corresponding to a minimum annual consumption for the savanna region of 5 million cubic metres, may be assumed. With allowance for institutional and industrial consumption, a total annual consumption of about 7 million cubic metres appears a reasonable estimate.

Sawnwood

Quantitatively, little information is available specifically in respect of the savanna region. From the figures in Table 3, a per caput consumption in 1960 of about 0.01 cubic metres of sawn output a year can be assumed in the 39 countries included; this is equivalent to 0.02 cubic metres of roundwood input.

The range is very great and reflects the differences between the more developed, industrialized countries and the more pastoral and agricultural ones. In the predominantly rural conditions of the savanna it would seem reasonable to assume that average current consumption is of the order of 0.018 cubic metres of roundwood equivalent per caput per year, or rather less than the average for western and eastern Africa as a whole.

With allowance for additional institutional and industrial needs, a total annual consumption of about 2 million cubic metres in the round can be assumed.

Qualitatively, the main demand is currently for general purpose building and joinery timber suitable for domestic and small institutional building purposes and for cheap furniture and domestic fittings such as cupboards, counters, bar tops, etc. Secondly, the demands are for strong hard-wearing timbers for such purposes as truck bodies and for heavy constructional timbers for railway sleepers and mining.

Demand for certain products may be very local. In and around large urban areas, such as Kano and Khartoum, requirements are more sophisticated than in the rural savanna areas, and include building materials such as rafters, lintels and window frames, and high-class furniture and panelling. Demand for mining timber is significant in specific areas, of which the copperbelt in Zambia and Zaire (Saba province) is the most important. Similarly, the use of wooden railway sleepers is variable; some railway administrations (notably Sudan) use them, but the majority do not.

COMBINED REQUIREMENTS

The combined annual requirements for fuelwood, roundwood and sawnwood in 1960 appear to be approximately:

	Cubic metres
Firewood	66 million
Roundwood	7 "
Sawnwood	2 "
Total	75 million

It must be emphasized that these figures are based on very slender data and they should accordingly be accepted only as indicative of the scale of present requirements. Nevertheless, they do give an idea of the requirements the savanna was called upon to meet in 1960 and of the relative consumption of the three main types of product.

Other wood products

Consumption both of panel products and of paper and paperboard in the savanna is still very small. Indications from FAO, 1967, in roundwood equivalent, are of an average annual consumption in 39 countries of 0.0015 cubic metres and 0.003 cubic metres per caput respectively. This would amount to only 150 000 cubic metres and 300 000 cubic metres for the whole savanna, assuming savanna areas had the same consumption per caput as the average for the whole countries; in fact it is likely to be considerably below the average.

Other products

In addition to the woody products mentioned above, the savanna is called upon to supply a number of other forest products. These include such materials as thatching grass, fruits, nuts such as those of the *Borassus* and "dom" (*Hyphaene*) palms and "Shea butter nuts" (*Butyrospermum paradoxicum*); fibres are also produced by the "dom" palms for rope making. Other minor products such as gum arabic, honey, beeswax and tanning products are also obtained from the savannas.

One or two of these "minor forest products" are of major importance locally. For instance gum arabic from *Acacia senegal* is the most important forest crop in Sudan. Export of the gum totals between 40 000 and 50 000 tons a year valued at about U.S.$15-20 million in 1966. This export value is exceeded in Sudan only by cotton and groundnuts. In addition to yields of the gum from natural forests of *Acacia senegal*, this species is also extensively raised in plantations on a large scale for the production of the gum.

Cashew nuts and cashew "apples" (from *Anarcardium occidentale*) are cultivated in savanna land in various countries. For instance in Senegal, some 5 000 hectares have been planted primarily as windbreaks to check soil erosion, but yield at the same time valuable crops of cashew nuts and "apples."

The pods of *Acacia nilotica* subsp. *adstringens* (syn. subsp. *adansonii*) are used for tanning. There is a big demand for them in northern Nigeria, and from both this variety and the ordinary *A. nilotica* large quantities are collected in Sudan.

Honey and beeswax are other minor forest products from savanna areas which in some countries are of considerable importance. In Tanzania for instance, exports of beeswax amount to 500 to 600 tons per year, valued at £200 000 to £240 000, while honey exports are valued at £50 000 to £60 000.

Future requirements

As a basis for forecasting future requirements, the following table has been derived from the FAO/United Nations Economic Commission for Africa study already quoted (FAO, 1967). It refers, again, to 23 countries in western Africa and 16 countries in eastern Africa, which contain substantial areas of land carrying vegetation other than savanna. Predictions of future demand are even more subject to imprecision than estimates of current demand. The table is thus no more than indicative of likely trends in the savanna region.

TABLE 4. — INCREASE IN DEMAND FOR WOOD PRODUCTS IN EASTERN AND WESTERN AFRICA

Type of product	Percentage increase in requirements beween 1960 and 1975
Fuelwood	29
Roundwood	37
Sawnwood	107
Panel products	173
Paper and paperboard	185

Fuelwood

In nearly every African country, the use of firewood and charcoal for industrial purposes has declined, being replaced by oil or electricity. This trend is more pronounced in respect of the bigger and more complex installations such as mines, cement and sugar factories and for railway use. It may be expected to continue.

On the domestic side there has also been some switch to other fuels in the richer urban areas but, because of the comparatively high cost of the alternative fuels such as electricity or kerosene, this switch is unlikely to go far in the near future. In the rural areas there has been very little swing away from wood as fuel, and it is unlikely that there will be much in the foreseeable future.

The overall picture is, therefore, one of appreciably declining industrial use of wood fuel, but of more or less static domestic use per caput. Taking into account that the population is likely to double by the end of the century, it may be predicted that demands for wood fuel will increase considerably.

Table 4 indicates an increase of about 30 percent in the 15 years between 1960 and 1975, equivalent to about 1.8 percent increase per year. If the same rate of increase were to continue steadily, fuelwood consumption by the end of the century would be approximately double that of 1960. In actual quantities this would rep-

resent a requirement of about 86 million cubic metres by 1975 and 112 million cubic metres by the year 2000.

Roundwood (poles, posts, etc.)

With rising standards of living there will be a demand for better housing and this is likely to involve some switch from the use of poles to sawnwood. A similar trend is likely to occur for institutions such as schools and dispensaries, the small " bush " building being replaced by a more sophisticated one.

On the other hand the increase of population that is expected will necessitate greater numbers of houses. As the amount of sawnwood that will be used in houses is likely to be small, the increase in pole requirements due to increasing population can be expected to exceed any decline due to switching to the use of sawnwood. Overall, in the field of domestic usage, a rise in future pole needs is predicted.

Similarly, in the industrial field, the rise in living standards can be expected to be accompanied by an extension of rural electrification and hence increased demands for power transmission poles. These at the moment constitute a very small proportion of the total consumption (e.g. only 0.005 percent of total wood consumption in Nigeria). Nevertheless, when required, they are essential and rarely available from natural savanna forests. Specifications tend to be high and, even if they are relaxed to the utmost, special plantations will be necessary to produce both transmission and telegraph poles.

Lastly, better agricultural and stock-raising practices are likely to require a considerable extension of fencing, and greater demands for fence posts can therefore be anticipated.

Thus, the picture for poles is likewise one of increasing demand, mainly for small poles for use in domestic building and for fence posts. Table 4 indicates an increase of nearly 40 percent in the 15 years between 1960 and 1975, equivalent to about 2.2 percent increase per year. If the same rate of increase were to be maintained, consumption by the end of the century would be between double and two and a half times that of 1960. Actual quantities resulting from this rate of increase would be 9.6 million cubic metres by 1975 and 16 million cubic metres by the year 2000.

Sawnwood

In considering the nature and extent of future demands for sawnwood in the savanna region, four factors are of importance, *viz*:

(*a*) the population is expected to double by the end of the century;

(*b*) living standards are expected to rise appreciably, creating a demand for better housing, better furniture and fittings and more of them;

(*c*) the per caput income of the savanna people is low;

(*d*) the prospects of large-scale industrialization in the savanna appear to be slight, because of the lack of raw materials, the smallness of local consumer markets and the distances, as a rule great, from large external markets.

The effect of factors (*a*) and (*b*) will be to create an increased demand for the raw materials used in house construction, furniture and fittings. For these purposes wood, in the form of sawnwood, is at present one of the customary materials. From (*d*) it appears unlikely that there will be any substantial local manufacture of alternative materials such as metals or plastics at cheap prices, and from (*c*) and (*d*) combined it seems unlikely that the average per caput income will reach such a high level that any great proportion of the people could afford to import alternative materials to wood, at least over any great distance.

The combined effect of the four factors, therefore, points to the conclusion that a substantial increase in the use of sawnwood can be expected in domestic building by the end of the century, and that any appreciable swing to alternative materials, such as metal or plastics, for purposes for which wood is now used, is unlikely within that time. For institutional and industrial purposes some increase can also reasonably be expected.

With regard to the types of timber required, there is little reason to expect any great change from the present pattern. There may be some increase in the demands for high-grade furniture timbers and for heavy constructional timbers but the bulk of the demand will probably continue to be for cheap, light, strong, easily workable and stable timbers suitable for general house building and joinery.

Table 4 indicates an increase of over 100 percent in sawnwood consumption in the 15 years between 1960 and 1975, equivalent to about 5 percent increase per year. If the same rate of increase were to be maintained, consumption by the end of the century would be seven times that of 1960. Actual quantities resulting from this rate of increase would be about 4 million cubic metres by 1975 and 14 million cubic metres by the year 2000 (roundwood input).

Panel products

Table 4 indicates an increase of about 170 percent in consumption of panel products (including plywood, veneer, fibreboard and particle board) between 1960 and 1975, equivalent to about 7 percent increase per year. If the same rate of increase were to be maintained, consumption by the end of the century would be 15 times that of 1960. Actual quantities resulting from this rate of increase would be about 0.4 million cubic metres by 1975 and 2.25 million cubic metres by the year 2000 (roundwood input). It seems likely that the rate of increase in the savanna will be appreciably lower than the average for the countries as a whole, which would result in lower requirements than the above. It may be noted, however, that a particle board factory is now in operation in Sudan at Khartoum, with an intake of approximately 13 250 cubic metres per year, in which it is intended to use savanna species as far as possible.

Paper and paperboard

Table 4 indicates that consumption of paper and paperboard is expected to increase almost threefold in the 15 years between 1960 and 1975, equivalent to slightly over 7 percent increase per year. This would amount to about 0.85 million cubic metres (roundwood input). Extrapolation to the year 2000 is virtually impossible, as so many unknown factors may arise, but it would not be surprising to find that requirements of pulp and paper were as much as 16 times their 1960 level (4.8 million cubic metres/year roundwood input).

Combined requirements

The above, admittedly highly speculative, predictions of demand may be summarized as follows (figures in roundwood input in every case):

Table 5. — Predictions of demand for wood products in savanna Africa

	1960	1975	2000
	Millions of cubic metres per year		
Fuelwood	66.00	86.00	132.00
Roundwood	7.00	9.60	16.00
Sawnwood	2.00	4.00	14.00
Panel products	0.15	0.40	2.25
Paper and paperboard	0.30	0.85	4.80

At this juncture it is of interest to examine the annual drain of these various types of products in relation to the area of the savanna. From the above table the total drain by 1975 is estimated at about 100 million cubic metres per year. On the estimated total area of the savanna region (13 million square kilometres), this would give an annual cut of about 8 cubic metres per square kilometre. This is equivalent to about 0.08 cubic metres per hectare or slightly over 1 cubic foot per acre. In practice, however, a great deal of the savanna region produces no wood products. No data are available as to the area of the savanna region yielding wood products, but even if it were as low as one tenth the annual cut would be of the order of 0.8 cubic metres per hectare. Over the whole, therefore, and excluding timber, it seems that natural regeneration and increment of the savanna should be adequate to sustain present needs. But this conclusion makes no allowance for the factor of distribution. Around the main concentrations of population the savanna is being cleared continuously for the extension of agriculture and stock raising, and is also subjected to heavy overcutting for forest produce. Although the overall picture may appear to be one of some adequacy of fuel and pole supply, there are many instances in which the local picture is one of serious shortage. Moreover, transport costs are likely to prohibit the supply of poles and fuel from distant sources at prices the people of the savanna can afford. Whatever the current overall position may appear to be, there can, therefore, be no complacency about the long-term adequacy of supplies from the savanna, nor does it in any way diminish the need to make provision for *local* supplies.

Protection and amenity requirements

The provision of adequate and well-regulated water supplies is likely to be the key to almost every form of development in the savanna region. At the same time, existing supplies will be subject to increasing strain as the human and livestock populations expand; in many areas they are barely adequate, particularly in the dry season. The protection of water catchment areas to ensure the maximum retention of water and a more even streamflow is therefore of dominant importance and will become increasingly so. More scientific information is, however, required for savanna conditions on the effects of forests and plantations on the water balance and on the extent to which the greater water usage by tree growth is compensated by the creation of better soil permeability and the reduction of water loss by run-off. The ancillary benefits of prevention of soil loss by erosion have also to be taken into account.

In many savanna areas, particularly where grazing is unduly heavy, soil loss by wind erosion may be a problem. Special measures to reduce this by planting shelterbelts may be necessary, and these may be combined with a productive function as, for instance, in Senegal where there is an extensive programme of establishment of windbreaks of cashew (*Anacardium occidentale*), primarily for preventing wind erosion.

As livestock populations expand there will be an increasing need for more and better grazing, and for the prevention of soil erosion. As agriculture and stock raising develop, with consequent clearing of forest and savanna growth, there will likewise be need for shade and shelter against desiccating winds and for the maintenance of equable atmospheric conditions, especially humidity. The special value of *Acacia albida* in this respect may be noted (see p. 42), as it retains its leaves during the hot weather giving shade, provides leaf fodder at a time when grass is scarce and is, in addition, a soil improver.

Lastly there is, and will be an increasing, need for greenbelts for amenity purposes near large towns. To some extent, these may be combined with productive purposes.

For all these purposes, advance planning of land use is essential. In some conditions the retention of belts or blocks of natural woodland for protective or amenity purposes may be as effective as, and much cheaper than, complete clearing of the existing tree crop followed by partial reforestation.

Conclusion

The foregoing paragraphs show that forestry has an important role to play in the economy and development of the savanna region.

On the productive side it will have to provide large quantities of forest produce. The most difficult and pressing problem will be in respect of sawnwood. Supplies are at present negligible and demands can be expected to build up to very considerable proportions by the end of the century, probably of the order of four or five times the present level. That period is already barely enough in which to produce sawlogs, while knowledge of the necessary techniques of doing so under savanna conditions is in its infancy. To work these out and to start the production of sawlogs on an adequate scale to meet the predicted future demands is one of the most pressing problems facing forestry in the savanna region today, and demands the most urgent attention. It also, of course, demands the longest-term planning and is the part of forestry most fraught with difficulties and hazards. Unless, however, it can be solved and timber produced locally at economic prices, the rise in general living standards that is sought will be much impeded. Pole and firewood production, on the other hand, is relatively easy. Techniques are well established and, since rotations are short for this type of crop, production need not be initiated so far in advance of predicted needs; there is consequently less risk of expensive planning errors. Moreover, there are considerable resources currently available on which to draw while extra supplies are built up.

The greatest relative increase in demand is predicted for pulp and paper products, but these start from a relatively low initial level. Pulp mills, to be economic, require a large annual intake, and how far it will be practicable or economic to provide the raw materials for this on the scale required from the savanna region is still a matter of conjecture.

There is another factor which affects production forestry. Much of the forest produce is at present derived from woodland that is not forest reserve. With rising human and livestock populations, much of this woodland will be put

to other use and lost to forest production. Already, in many areas, there are marked shortages of produce near towns and in high population-density areas. If forestry is to fulfil its role of providing supplies of forest produce to meet the predicted requirements, *it is essential that sufficient land for this purpose, either bearing forest or capable of afforestation, be selected and set aside for forestry within reasonable distance of consuming centres as soon as possible, before it is lost to other uses.* That, in turn, requires an early appraisal of the future demands for forest produce likely to arise in each country, i.e. for a consumption survey and forecast (see p. 21-23). Forward estimates of land that will be required for agriculture, grazing and other purposes should be made at the same time, and the allocation of land for long-term forest production should be based on an integrated land-use plan taking all these requirements into consideration. It should pay particular attention to the need for reserving forest land for protective purposes.

This protective function of forests for the conservation of water supplies, the protection of catchment areas, the prevention of erosion, the provision of shelterbelts and amenity forests and the maintenance of equable climatic conditions locally, by the retention or creation of large blocks of forest, is often of even more importance than the productive function; and implementation of this protective role requires the early dedication of appropriate areas as permanent and inviolable forest reserves.

4. THE PLACE OF FOREST PLANTATIONS

The preceding chapter surveyed the roles to be played by forestry in the development of the savanna region. The next step is to consider the part to be played by plantations in the implementation of these roles.

As has been indicated, wood of certain types and quality is in short supply over much of the savanna region; and in order to meet present and future requirements, large-scale plantation operations will be needed on sites that are often initially inhospitable because of limited rainfall, frequently combined with infertile and impermeable soils. The soil deficiencies can usually be overcome at a cost, but climatic shortcomings are not subject to control, though the effects of shortage of water can often be mitigated by measures taken to prevent run-off and conserve as much of the rainfall as possible. All this costs money, and, in general, plantations in savanna areas are likely to be more expensive and lower yielding than those in high-forest zones. The economics of savanna plantations, therefore, need careful watching.

Production

Fuelwood

Qualitatively, the requirements for fuelwood are not, for the most part, exacting and the natural savanna woodland can generally provide fuelwood of an adequate quality. Its main shortcomings are low stocking and poor form, which lead to extensive harvesting and low solid volume per stack of fuel. Neither of these is of much consequence for domestic supplies in sparsely populated regions, but both may be of significance in the vicinity of large towns and centres of dense population or where large supplies are required for industrial purposes.

Provided it exists in sufficient quantities, the savanna woodland is usually adequate to meet the demands for fuelwood that are made on it, and its outturn can, moreover, be raised to a limited extent by appropriate silvicultural treatment, e.g. coppicing coupled with fire control through early burning. Consequently, with respect to fuelwood, the role of plantations is to provide supplies in areas where natural woodland is lacking or inadequate to meet local demands, or where special industrial requirements for large quantities of particular specifications have

FIGURE 7. Three-year-old *Eucalyptus camaldulensis* in the savanna of western Sudan.

(*Courtesy* H.R. Schoenwald)

to be met. Fuelwood plantations will normally be located in relatively small units close to centres of domestic consumption, to supplement the natural bush or woodland as sources of supply, or in larger special purpose plantations as near as possible to a fuelwood-using industry.

Roundwood

As in the case of fuelwood, the natural savanna woodland can produce substantial quantities of poles, but the quality of these and the stocking of them in the forest often leave much to be desired. The main defects in quality are lack of length, straightness and durability. At the present low standards of housing these are not of much consequence but, as standards rise, and for industrial purposes (e.g. telegraph and transmission poles), demands will be for higher quality poles than the natural woodlands can produce. At present, therefore, the main function of plantations is to provide supplies of building and industrial poles in areas in which suitable natural woodland is lacking or where it is necessary to make more intensive use of the land. But as standards rise and the quantities needed increase, an extension of pole plantations into areas where natural woodland still exists is probable in order to provide the larger quantities and higher qualities of poles that will be required.

Plantations for poles and fuelwood can be, and in most cases are, combined and managed for the dual purpose, but for some rather exacting uses, such as large transmission poles, plantations managed primarily for that purpose may be necessary.

Sawnwood

With a few exceptions the savanna does not produce good indigenous workable sawnwood in quantity. The majority of species occurring naturally in the savanna have hard, heavy woods, difficult to season and work, perishable, of small size and of poor form; they are thus not at all well suited for the main purpose for which they are required, namely general house construction and joinery. Only a few have good working qualities. These include *Pterocarpus angolensis* (muninga) from east and central Africa, which is an outstanding timber, *Baikiaea plurijuga* (Rhodesian teak) and *Guibourtia coleosperma* (Rhodesian copalwood) from central Africa, *Afzelia africana* and *A. quanzensis*, *Khaya senegalensis* (dry zone mahogany), and in certain areas of derived savanna, *Chlorophora excelsa* (Mvule, Iroko). Others are of course used; some of them, such as *Isoberlinia* and *Brachystegia*, in considerable quantities in some countries, but their intrinsic qualities are poor and they are used because of lack of anything better.

The stocking of merchantable timber in the savanna is usually very low. For example, it is not unusual for the stocking of mature harvestable *Pterocarpus angolensis* (muninga) trees in unreserved woodland to be as low as one or two trees per square mile (about 2.5 square kilometres) and the majority of these do not yield more than one log or about 0.7-0.8 cubic metres per tree. Some of the *Isoberlinia* and *Brachystegia* on the other hand (e.g. *Isoberlinia doka* in southern Sudan) occur locally in quite dense stands. In general, however, the low stocking makes harvesting expensive despite the easy terrain that commonly prevails, and the poor form and small logs obtainable from the trees make recovery low, so that the resulting sawnwood is expensive to produce per unit, in relation to its qualities. This is hardly conducive to its use.

Because of:

(*a*) the poor quality of the majority of the species,
(*b*) the low stocking of the better quality species and their slow growth,
(*c*) the lack of knowledge of the factors governing successful regeneration and lack of experience in techniques of natural regeneration and silviculture,

the prospects of significantly increasing the output of useful sawlogs by regeneration and silvicultural treatment of the natural forest appear remote. Some trials of such silvicultural methods have been made in Zambia (Endean, 1962) in " miombo " (*Brachystegia - Isoberlinia*) woodland, but have given an increase in production after 25 years of, at best, only 10 percent over the control. Improvements of this order are of little significance compared with the increased requirements of sawnwood predicted, and it must be concluded that there can be little prospect of providing future sawlog requirements by regeneration and silvicultural treatment of the natural

savanna woodland. Future requirements must, therefore, be met almost entirely by plantations.

Harvesting and processing are generally more economical in large units. For this reason it is advisable to concentrate sawlog plantations into as large units as conditions permit; but lack of homogeneity in savanna soil conditions may preclude this. Also, concentration into a few large units may mean that supplies have to be transported considerable distances to some consumer centres and this defeats the aim of producing cheap, readily accessible supplies of sawnwood. In practice, the distribution of sawlog plantations usually involves some compromise but, under savanna conditions, the overriding factor will, as a rule, be the occurrence of good sites.

Pulpwood

If pulpwood is required in the savanna region it will almost certainly have to be produced by means of plantations, on account of the very large quantities of uniform suitable material required within economic distance of a pulp mill. The problem of obtaining large areas of uniform soil conditions has been mentioned above under sawnwood, but applies still more to pulpwood plantations.

General

Whether the main object is the provision of fuel, poles, sawnwood, pulpwood or supplies for other industrial processes (e.g. particle board manufacture), it is certain that, in order to be economic, plantations must achieve reasonably high rates of growth. The figure that can be called reasonable will vary widely with local conditions, with cost of establishment, value of the product, distance from the market, etc., but plainly, plantations will mostly be restricted to the physically better (i.e. deeper and more permeable) soils and to those localities where adequate soil moisture is available to the tree roots at critical times of the year. The species grown must be of adequately fast growth under the conditions in which the plantations are made. Few indigenous savanna species are likely to provide an economically acceptable rate of production and few sites in the more arid zones will be suitable for economic plantations of any species, indigenous or exotic, unless subsoil water is available from extraneous sources. Where irrigation is available, highly productive plantations may be raised in very dry areas, especially if, as in the case of the Khartoum greenbelt, the sewage effluent of a large city can be used for irrigation (Bosshard, 1966b). Successful irrigated plantations have also been made in the Sudan Gezira and again in the west Pakistan desert, and any opportunity for using irrigation in savanna planting should be taken.

Protection and amenity

For the majority of protective and amenity purposes it is unlikely that plantations will be employed, because:

(*a*) the natural woody cover is usually adequate for these purposes;
(*b*) if not, sufficient woody cover can usually be obtained by natural means, e.g. by fire protection, canopy manipulation and closure to grazing, in order to stimulate natural regeneration;
(*c*) establishment of woody cover by such means is, as a rule, much cheaper than forming plantations.

The most likely use of plantations for protective purposes will be for narrow shelterbelts, which cannot be established by natural means, and to protect the margins of catchment areas of dams. Such plantations are not likely to be extensive but they may, at the same time, fulfil a productive role. Such protective plantations are particularly likely to be wanted in the vicinity of large towns where the natural forest has disappeared. For instance, one of the functions of the irrigated plantations in the Khartoum greenbelt is to provide protection against "haboobs" or dust storms from the south, as well as amenity for the large population of the city.

Conversely, it is possible that productive plantations might be established in place of natural woodland on catchment areas or riparian sites, because of the suitability of the site conditions. In such circumstances the relative effect of the plantations and the natural forest for protective purposes must be taken into account. No significant examples of such a transposition in the savanna zone are known at the time of writing but, with the need for expanding plantations in the future, it is possible that they will arise.

Part II

CHOICE OF SITE AND SPECIES

5. CHOICE OF SITE

Site conditions, particularly the depth of soil and its capacity to retain moisture in the dry season, frequently vary greatly over quite short distances in the savanna region. These two factors are probably the most important for successful planting. There are numerous plantations which demonstrate errors in the choice of site or failure to give it sufficient attention.

Although experience in the assessment of site factors and their interpretation, in terms of tree growth, is being rapidly accumulated through research, it is still often inadequate for making a reliable forecast of the suitability of a particular species for planting and of its productivity on a given site. The two main ways in which the suitability of sites for plantations can be assessed are (1) by a study of the existing vegetation, and (2) by a study of the soil, particularly its physical properties, in relation to the climate.

In areas which have not suffered much interference by man, the vegetation can, to some extent, provide an indication of the site. For instance, in Sudan various *Acacia* associations are recognized as indicators of site conditions and in other areas individual species may be useful in estimating soil conditions. Examples are:

Acacia seyal — generally indicative of soils which are heavy, clayey and badly drained

Acacia polyacantha subsp. *campylacantha* — indicative of moist alluvial soils

Borassus aethiopum, *Hyphaene thebaica* — often indicative of poorly drained soils with a shallow water table, although not occurring exclusively on such soils

Copaifera mopane — indicative of soils subject to temporary flooding and becoming very dry after the rains

Baikiaea plurijuga — indicative of the Kalahari sands

Mitragyna inermis — indicative of temporarily marshy or flooded areas

Parkia clappertoniana, *Butyrospermum paradoxicum* — characteristic of cultivated land and generally indicating good soils

Terminalia macroptera — often, though not invariably, indicates poorly drained soils

Over much of the savanna region, however, the vegetation has been so disturbed by past cultivation and burning that it is no longer a reliable indicator of planting sites, and site selection must be based on soil survey. Indeed, even where the vegetation appears to provide a means of site selection it is advisable to supplement it with soil surveys as there may be differences of soil depth and permeability which are hardly reflected by the vegetation but which may be of importance to an exotic plantation species.

In this connection, a knowledge of the depth and variation of the water-table levels in the wet and dry seasons, especially the latter, is valuable and may be crucial in determining what species can be grown. It can be ascertained from observations in wells or by special borings made for the purpose. More information is needed regarding the minimum water-table levels and the range of fluctuation of the levels that can be tolerated by different species with differing rooting habits. For instance, in Nigeria in Afaka Reserve, the water-table level ranged from a maximum depth of 7 to 11.5 metres (23 to 38 feet) in the driest part of the year to a minimum depth of 3.4 to 10 metres (11 to 33 feet) in the wet season (data from 3 stations), with a varation of usually about 3.4 metres (11 feet) between

the wettest and the driest season. Soil moisture determinations in the same region showed that *Eucalyptus* trees used moisture down to 4.6 metres (15 feet). Important differences between species have been found in their root penetration and ability to reach and utilize subsoil moisture.

Intensive studies of water-table levels and of soil moisture distribution and its depletion by tree crops are being made on savanna soils in northern Nigeria but it is too early to be able to interpret them in terms of the plantability of sites and the growth of different species.

A method of soil survey is practised in Zambia which has proved of great value there for the determination of the location of plantations of eucalypts and pines. Briefly, the procedure is that areas suggested for afforestation are first mapped, usually from air photographs. The soils of the area are then systematically sampled by means of soil pits. The usual procedure is to run a series of parallel lines across the area following the slope, if there is one, and to site the pits at regular intervals along them. The lines may be several hundred metres apart and the pits some 90 metres (100 yards) or so apart in the lines, the spacing depending on the amount of background information available, the variability of the site and the precision of the information required. For each pit the profile data are recorded on punch cards. The data recorded are colour, texture, degree of compaction, moisture content, presence and description of impediments and rocks, and effective depth of soil, with additional notes on the humus, vegetation and any unusual features. In assessing texture and colour, most attention is paid to the soil between 0.6 and 1.2 metres (2 feet and 4 feet) depth as it is in this zone that most tree roots of plantation species are found. The top soil, i.e. the first 15 to 23 centimetres (6 to 9 inches) is usually disregarded except for chemical analysis, as it is commonly so disturbed by grass fires and past cultivation that little of value to the forester can be gleaned from its study. Close attention is paid to the presence of zones of impediment, e.g. laterite or murram, and to the effective depth of the soil, i.e. the depth to which tree roots can penetrate. Care must be taken, however, since the apparent depth of soils as estimated from the presence of impediments in the profile is often not the effective depth. *Pinus kesiya* roots, for example, can penetrate laterite and the tree will often continue to take up water and grow when the profile above the laterite layer is quite dry (Greenwood, 1969). For optimum growth of pines and eucalypts an effective depth of at least 1.8 metres (6 feet) is sought.

By sorting these data, soil types are distinguished and then mapped. This soil map and a geological map are then superimposed on an air photo mosaic of the area which records the vegetation, and from these maps the sites which are considered suitable for planting are located. The reason for superimposing the geological map as well as the soil map is that in Zambia the same soil type has been found to give very different results over different underlying geological formations, and where these different formations occur under the same prospective planting area it is necessary to distinguish between them. In areas of uniform geology only the soil map would be applied. The method is described in more detail by Savory, 1960.

Similar methods of soil survey based on the Zambian practice have been developed in northern Nigeria. Prior to the field work, literature, maps and air photographs were intensively studied, and for field work the air photos were enlarged to a scale of 1:15 000, and the soil type boundaries drawn on them. The soils were examined and described from pits and from cores extracted either by means of a Giddings hydraulically powered soil corer mounted on a Land Rover or, in places inaccessible to a Land Rover, by hand augering.

In checking soil boundaries small pits to a depth of about 90 centimetres (3 feet) were dug followed by augering for a further 120 centimetres (4 feet). The mean density of sampling was about 2.7 pits per square kilometre (7 per square mile) in cultivable areas. Details of the methods used and the classification adopted are given by Barrera and Amujo, 1969.

In Sudan, the variation in forest vegetation within general types clearly indicates the need for soil mapping. For instance it was observed during the forestry survey for the United Nations Development Programme Kordofan project that the natural distribution of *Acacia senegal* is related to the underlying geological formations beneath an otherwise apparently uniform vegetation type. Over the whole of the sandy peneplain the characteristic vegetation is *Combretum - Albizia - Terminalia*. Where this peneplain overlies the basement complex, *A. senegal* is present

as a minor constituent. Where the underlying formation is the Nubian series, it is absent. The reasons for this are obscure and require investigation, so that the particular soil factors favouring the growth of the economically valuable *Acacia senegal* can be determined.

The interpretation of soil survey data in terms of choice of species, rates of growth, etc., can usually only be made as a result of plantation experience. For instance, in northern Nigeria it was found that on a nutritionally rich soil with a high wet-season water table, pines were only half as tall as those on a less fertile soil with better drainage. *Acrocarpus fraxinifolius* roots penetrated to depths of 4.5 metres (15 feet) on a eutrophic brown earth and only to 0.9 metres (3 feet) on a dense ferruginous tropical soil, and growth was much poorer on the latter. High bulk densities are found in the subsoils on many sites and are generally unfavourable, impeding the root development of many species. As subsoil bulk density often varies over short distances without giving rise to observable surface characteristics, satisfactory mapping of soils for the location of large-scale plantations can sometimes be difficult. Nevertheless, in order to avoid clearly unsuitable conditions and to be able to extend the planting experience on one site to others with similar characteristics, systematic soil surveys are usually an indispensable preliminary in all large-scale plantation projects.

Soil fertility

Stress has been laid so far on the need for suitable physical conditions in the soil in the selection of plantation sites, and it is axiomatic that for satisfactory growth the physical conditions must be favourable. This is the first priority in site selection.

Nevertheless, infertility may also be an important cause of poor tree growth, but fortunately this can usually be remedied artificially which is less often possible for unfavourable physical conditions. Evidence of the importance of fertility can be seen by the growth of trees on termite mounds where they are sometimes twice the height of the rest of the plantation and a much darker green, indicating more available nitrogen. Trees growing on patches where woody debris has been burned are often greatly superior to those on unburned soil. Trees planted on abandoned farm land often exhibit differences in growth rates associated with former agricultural treatments. And there are the results of many fertilizer trials which provide direct evidence of nutrient deficiencies.

Many savanna soils are relatively infertile, having low base-exchange capacities and low levels of available nutrients, and are moderately to strongly acid. Repeated grass fires destroy organic matter and bring about other changes affecting fertility. Nitrogen is lost in the burning and although other nonvolatile elements are returned to the soil after fire, many of them may be lost through erosion and leaching.

Fertilizer experiments made with various eucalypts, pines and teak in Sudan, north Guinea and derived savanna zones of Nigeria show that phosphorus, nitrogen and boron are the elements most commonly deficient. Potassium deficiencies are rare. Phosphorus is the element most commonly deficient. Nitrogen, especially when applied with phosphorus, often results in increased growth but, in some cases when applied alone, it can depress growth. On some sites, total phosphorus may seem adequate but the plants may still respond to further additions of phosphate fertilizers. Large quantities of phosphorus may be fixed and unavailable to plants due to the high iron oxide content of ferruginous soils combined with low pH.

As regards nitrogen, there is evidence that this element may become deficient for growth on some sites during the latter part of the rainy season. There is usually a release of available nitrogen at the beginning of the rains, either from the litter of the previous dry season or on the wetting of the clay fractions of the soil or both, but this may be rapidly used up or lost through leaching.

Boron deficiency is sometimes found in savanna soils and may affect some species, notably certain eucalypts, in which it causes die-back symptoms and a reduction in growth. Fortunately it is easily remedied by the application of borate fertilizers.

In carrying out soil surveys for selection of sites for plantations, therefore, attention should be paid to the nutrient status of the soil. Sites that are satisfactory physically but poor nutritionally should not be rejected unless and until fertilizer experiments have shown that the nutrient deficiencies cannot be economically remedied by application of fertilizers.

6. CHOICE OF SPECIES

General considerations

The choice of species for savanna afforestation will depend firstly on the purpose of the planting and the type of produce required, and secondly on what species can be grown well under the climate and soil conditions of the land available for afforestation. Other considerations which will affect the choice of species are the ease with which they can be raised and established, their relative profitability and their utility for more than one purpose.

As has been indicated in the preceding part, the indigenous savanna species have a number of shortcomings as providers of forest produce. These are most serious in respect of timber, but even for firewood there may be deficiencies of form and rate of growth. In most cases, therefore, the choice has been and will continue to be directed first toward exotics which can give a product better suited to the purposes required, a faster rate of growth and a higher yield per hectare. This will be more pronounced in the case of timber and poles than of fuel. The choice of indigenous species has been confined to a relatively few cases in which they have proved superior to exotics, both for purpose and site adaptability. An example is *Acacia nilotica* in Sudan which is grown on seasonally flooded areas near the main rivers. But even in these cases, trials of exotics are likely to continue in the search for a better quality product and higher production.

In savanna areas the main factors which may limit growth are:

1. Seasonal deficiency of water. This is a major cause of slow tree growth, low yields and drought casualties.
2. High temperatures. Evergreen species (e.g. eucalypts, pines and others) may suffer from excessive transpiration stress during high dry-season temperatures, or may produce abnormal growth.
3. Unfavourable soil profiles often with impermeable indurated horizons requiring powerful and robust mechanical equipment to create favourable plantation conditions. Growth may be limited, either by the physical inability of roots to penetrate such horizons, or by the inability of rainwater to enter the soil so that it is lost to the site by run-off.
4. Nutrient deficiencies. These are common on savanna soils, particularly phosphate and nitrogen among the major nutrients, and boron among the minor nutrients.
5. Pests and diseases.

All the above have to be taken into account when selecting sites and species and, where the adverse factors cannot be controlled easily and cheaply, species and provenances must be chosen that are resistant to the particular adverse factors in the locality to be planted.

Photoperiodism is another factor that may affect the growth of exotic species imported from higher latitudes.

The most important criteria for selection of species are adaptability, suitability of produce, ease of handling, coppicing ability and availability of seed.

Adaptability

While generally preferring species that come from similar ecological conditions and climatic regimes, there are numerous examples of exotics growing very successfully in climates and latitudes far removed from those of their native habitat. In view of this it is dangerous to apply the concept of homoclimes too rigidly when selecting species for trial, and, from the ecological point of view, one should spread one's net wide. Features to look for are plasticity and relative

adaptability to differing conditions and what can only be described as general "toughness," in the sense of ability to stand conditions more severe than those the species normally experience.

Suitability of produce

Species selected must be capable of fulfilling the function for which they are being introduced, and this implies that the objectives for any species trial programme must be clearly defined in advance. If the production of wood in any form is the objective, rapid growth and high volume production are essential. If the wood is to be used for fuel, a high calorific value is desirable, as well as absence of sparking when burnt; if for poles, the trees should be straight, round and of adequate strength; if for timber, in addition to having good stem form the wood itself must have all the qualities (e.g. stability, strength, durability, working properties, etc.), when grown under plantation conditions, to make it suitable for the end uses envisaged; if for pulping and paper making, usually fibre length, thickness and colour are important. Much time and money can be wasted on species trials and on plantations if the wood of the species grown turns out to have technical properties that are unsuitable for the intended uses. On the other hand, if a species can serve more than one purpose, so much the better, as this will lead to closer utilization.

Ease of handling

The species should be easy to handle in the nursery and in the field. To start with this may be difficult to judge as suitable techniques for raising and planting it may have to be developed. It should preferably be fast growing in early youth so as to minimize the time and cost of the establishment phase.

Coppicing ability

Good coppicing ability is an asset, particularly in crops grown for fuel, or for bulk cellulose (pulpwood), or for particle board manufacture.

Availability of seed

Seed from reliable sources should be readily available annually in adequate quantities. Trees that produce seed at long intervals are only acceptable if the seed can be stored without deterioration, or if the young plants can be stored in nurseries for several years to meet the planting programme during the period when seed is unavailable.

Species trials

A large number of trials of a great variety of species have been carried out in the savanna region but many of them have been unsystematic, unreplicated and poorly recorded. In consequence it is often impossible to be certain of the precise origin of the species tried or the history of its trial, or that the trial has covered all the factors of the site. It is, therefore, frequently impossible to be sure whether a particular species has failed because it was unsuited to the locality, or had bad treatment, or suffered particularly adverse conditions after planting, or whether another has succeeded because it was intrinsically well suited to the conditions or because of good luck. These difficulties are aggravated by the fact that a species has frequently done well in one place and, for no evident reason, failed in another, under apparently similar site conditions. The whole pattern of species trials in the savanna region demonstrates the great unpredictability of results and the need for systematic and fully replicated trials of species as

FIGURE 8. Lining out and hole digging on a cleared site for experimental plots in western Sudan. Plots are 7 × 7 trees, of which the inner 5 × 5 will be measured. Woody vegetation was piled and burnt between plots in order to avoid any possible differential burning effects within plots. The black strips are caused by the ash residue after burning.

(*Courtesy* M. Reynders)

the basis of choice for field planting. It cannot be too strongly emphasized that without such trials, choice of species is, in most cases, an extremely chancy business. Since afforestation in the savanna region is normally an expensive undertaking, large-scale failures, which may result from wrong choice of species and failure to test them on a small scale, can prove extremely costly.

Procedures for species trials have been greatly improved in recent years and very similar systems have been worked out and applied with success in Nigeria, Uganda and Zambia.

Accounts of these have been published (Cooling, 1962; Edwards and Howell, 1962; Kemp, 1969, 1970; Leuchars, 1962) and merit careful attention from anyone undertaking savanna planting.

Broadly, the trials are carried out in three stages as indicated below. In some cases the stages have been telescoped to a certain extent, sometimes with unfortunate results.

Stage 1. Species elimination trials (SET)

In these, the species are planted in small arboretum-style plots of 16 to 20 trees or so, the object being to test a wide range of species and to eliminate the useless ones as cheaply and quickly as possible. Because some species are slow starters while others may show early promise, these screening or arboretum plots are assessed for at least five years and a species is not regarded as a write-off in less than that period.

Each species plot is repeated two or three times on the site at the initial planting, and may be further repeated in subsequent years so as to obviate unwarranted rejection on account of chance causes such as local termite trouble, animal damage or a particularly bad season. Records of survival, health and height growth are made. Failures, with the cause if possible, are recorded as carefully as successes.

Though the small size of plot and early edge effect between plots render quantitative measurements unreliable after the first few years, much useful information about comparative initial performance can often be gleaned from the replicated plots. The main object, however, is the elimination of species that show no promise and the identification of adaptable species worth further trial.

Stage 2. Species growth trials (SGT)

This is the small plot species performance stage in which those species that have shown themselves promising in the first (SET) stage are further tested in rather larger plots, generally of at least 400 square metres (0.1 acres) and containing 60 to 120 trees according to spacing. It is essential that these small plots be laid out in a proper, randomized, replicated design capable of statistical analysis, and it is highly desirable that such designs, and especially the methods of assessment, should be standardized, both for existing trials and new plots, so that the performance of a species under different conditions and in different localities can be compared. Assessments of record survival, health, height, girths or diameters, and later on such characters as straightness of bole, branching habit, etc., are made annually for the first three or four years, after which the assessment interval may be increased to two to five years. The duration of Stage 2 trials varies from 15 years (Nigeria) to a whole rotation (Uganda).

Stage 3. Crop performance trials (CPT)

This is the large plot testing stage in which crop performance is assessed. Species which are promising in the small plot stage (SGT) are further tested in larger plots of 0.4 to 2 hectares (1 to 5 acres), though some authorities are satisfied with smaller plots of down to 0.2 hectares (0.5 acres). The object is to obtain quantitative data of crop performance under plantation conditions and, at the same time, more experience in planting and tending on a larger scale. Assessments follow usual " sample plot " procedure and are made on an inner central plot within an unmeasured surround. Some replication is desirable but its degree is usually limited by the large size of individual plots. The plots are intended to provide comparative data on increment and yields per unit area for main crop as well as thinnings.

In Uganda, the Stage 1 (SET) plots are put in as standard practice at all potential planting areas. If planting is seriously considered, Stage 2 (SGT) plots of the most likely species are replicated, both in area and time over a period of five years. By this means it is hoped to obtain a sound assessment of the performance of the chosen species over the range of sites to be planted and over a number of planting years.

Usually, completion of the earlier stages is not necessarily awaited before the later stages are started; the latter are started as soon as it becomes apparent from earlier stages what species seem to merit further trial.

In selecting species for Stage 1 trials, the criteria mentioned on p. 38 should be observed. Within the limitations mentioned there, particularly refusal to consider species that for technical reasons are unlikely to fulfil the objectives of the plantations, as wide a range as possible of species should be tried, including those from habitats differing from that in which they will be grown. It may be expected that many such "wide shots" will fail and be eliminated in the Stage 1 trials, but now and then species are found which are so adaptable that they thrive and produce valuable results under conditions differing widely from those of their native habitat.

As is well known, differences in provenance of a species may result in very different performances. It is, therefore, desirable in species trials to try also several provenances, especially of species having a wide geographic range. Edwards and Howell, 1962, have suggested as a rough rule that at least three provenances of a new introduction should be tested, namely:

(*a*) the best climatic match;
(*b*) from the region of optimum development in its native habitat; and
(*c*) a further provenance extending the range in an important direction (e.g. to a soil type having close affinity with that of the proposed planting site).

At a later stage of research, it may be necessary to carry out range-wide provenance trials of those species which have proved successful in species trials and which are known to occur over a wide range of ecological conditions. A number of international provenance trials, conducted to a standard procedure, have been laid down recently (Burley and Cooling, 1971; Cooling, 1968b; Lacaze, 1970; Turnbull and Burley, 1971). Adequate experimental design is essential for provenance trials and, when the trial includes a large number of provenances, one of the more complex designs (such as a lattice design) may be called for; advice should be sought from a biometrician. During the conduct of species trials, as opposed to full-scale, range-wide provenance trials, the important points are:

(*a*) to consider including more than one provenance of certain species;
(*b*) to be able to identify the source of *all* seed lots used in the trials.

Hybridization

Hybrids between related species may result in better survival and increased rate of growth, and the testing of hybrids is likely to be fruitful, especially in the case of eucalypts, many of which hybridize readily. Examples of eucalypt hybrids which show considerable promise in Nigeria are those between *E. camaldulensis* (or *E. tereticornis*) and *E. grandis* (or *E. saligna*), and between *E. citriodora* and *E. torelliana* (FAO, 1970a). Zambia also has reported promising results of the *E.* "*grandis*" × *E. tereticornis* hybrid (see p. 60 for discussion of *E.* "*grandis*" terminology). Naturally occurring hybrids should therefore be looked for, both in their countries of origin and in plantations, and should be included in species trials. At a later stage, studies of artificial hybridization, both intra- and interspecific, through controlled cross-pollination, should form part of any tree breeding programme.

7. EXPERIENCE WITH INDIVIDUAL SPECIES

In a general publication of this nature covering the whole of the savanna region, and in the light of the foregoing paragraphs on the choice of species, it is clearly not possible to make any precise recommendations of species for savanna planting in any given locality. So much will depend upon the local circumstances, as regards both requirements of forest produce and the experience with species trials. Much useful information has been published (Bosshard, 1966a; Champion and Brasnett, 1958; Cooling and Endean, 1966; Goor, 1964; Goor and Barney, 1968; Kemp, 1969, 1970; Métro, 1955; Parry, 1956; Streets, 1962).

As a supplement to these, the following brief notes indicate experience to date with selected species tried for savanna planting in Africa. They are grouped according to Aubréville's main climatic types described in Chapter 2, i.e. 1, desert; 2, subdesert; 3, dry tropical; 4, semihumid tropical; 5, humid tropical and equatorial.

Climatic type 1. Desert

Excluded from consideration in this manual.

Climatic type 2. Subdesert

The subdesert is characterized by an extended dry period (8-11 months) with very high mean annual saturation deficit and potential evapotranspiration. Rainfall is 200-400 millimetres, irregular and very unreliable in occurrence.

In the absence of subsoil moisture, economic tree planting is rarely possible in such dry areas. However, where a local high water table or seasonal flooding from rivers occurs, or where irrigation is possible, several species can be grown successfully. With the exception of *Acacia senegal* and *Prosopis chilensis,* all the species mentioned below depend on extraneous water supplies for satisfactory growth.

Acacia albida Delile (Haraz)

This large acacia is found throughout the drier zones of Africa from southern Algeria to the Transvaal and from the Atlantic to the Indian Ocean. Relatively uncommon in the natural forests, it is a prominent tree on cultivated areas. It occurs on permeable sandy or silty soils where the water table is accessible to the tree roots, and is not dependent on local rainfall once it is established. It is found in localities with only 250 to 400 millimetres of rain per year. It does not grow well on lateritic soils or soils with impeded drainage. While it will withstand short periods of flooding, it does not do well under irrigation, especially on heavy soils. It is fairly frost resistant. It develops a massive root system of a tap-root type.

The tree is particularly valuable in agricultural areas on account of its unusual habit of retaining its leaves during the hot weather and dropping them during the rains. The pods and leaves are very good fodder and the pods, prolific crops of which are produced annually, can be stored. The pod and leaf fall, together with the dung and urine of cattle that seek the shade of trees in hot weather, improve the nutrient status and physical condition of the soil, so that yields of sorghum and other agricultural crops cultivated during the rains are considerably increased. The cattle-carrying capacity of the land is also improved where this tree is present, on account of the excellent leaf and pod fodder produced at a time when grass is scarce. It is therefore an important tree in village economy and, in some regions, is declared a protected tree.

The wood is rather soft and is easy to work and is used for building construction, rough carpentry and joinery work. It is, however,

liable to stain and to attack by borers and is an indifferent fuel.

It is grown as a scattered tree and never in close plantations. The seed (11 000 per kilogramme) is collected in April and has a high germinative capacity. It keeps well and 12-month-old seed is as good as fresh seed if free from insect attack. In Senegal, two to three seeds are sown in each polythene pot after soaking for 48 hours. Plants are singled after one month, and after four months they reach 10 to 15 centimetres in height and have filled the pots with roots. Planting in August in simple pits, frequently along with cultivated crops — often millet — on agricultural land is the normal practice (Senegal), but straightforward pit planting has been successful on dunes or fallow land. After planting, height growth is negligible to start with, but the root system develops rapidly. By about the third year, when the roots have reached subsoil water, the tree starts to grow vigorously. It is then no longer troubled by weed or crop competition and becomes one of the fastest growers (apart from some eucalypts) in dry areas. In some places it is still raised by direct sowing, but this is much less reliable and many failures have been recorded. The tree coppices readily and vigorously (Bosshard, 1966a; Giffard, 1966; Radwanski and Wickens, 1967).

Acacia nilotica (L.) Willd. ex Del. — Syn. *A. arabica* (Lam.) Willd., Sunt (Arabic), Babul (Urdu)

Native of India, Arabia and north Africa, it occurs typically on soils that are seasonally inundated. In Sudan it is found chiefly in small basins at the bends of the larger rivers which are flooded when the rivers are high, and in such situations it is intensively managed and cultivated. It is also found along temporary water-courses and in depressions. It is highly drought resistant provided it gets the equivalent of at least 400 millimetres of rainfall in the form of rain, floodwater or irrigation. It tolerates high temperatures (up to 50°C) but is not frost hardy. It is recommended for plantations in its natural habitat or in similar conditions.

The wood is hard and heavy, dark red in colour and very durable. It is used for railway sleepers, sawn timber for many purposes, building construction, native beds, boat building, etc., and also for poles. It is an excellent firewood. It is by far the most important species in the arid zone of Sudan.

Regeneration is mostly by direct "spot" sowing in shallow pits using seed that has been pretreated with concentrated sulphuric acid for 60 minutes, though broadcasting is also practised. About 8 000 seed go to the kilogramme, and broadcasting and "spot" sowing require respectively about 30 kilogrammes and 6 kilogrammes per hectare. Thorough weeding is necessary for the first two years and seedlings should be thinned out to one per pit (or to a spacing of 2 × 2 metres if broadcast) when about 60 centimetres high. Pit sowing has been successful in conjunction with taungya cultivation.

The trees are commonly of poor form and coppicing power is negligible. Single tree growth statistics have been published (Waheed Khan, 1966c).

A. nilotica is divided into a number of subspecies, most of which occur on seasonally inundated flood plains. Special mention should be made of the subspecies *adstringens* (previously *adansonii*), which is adapted to growing on dry sites away from rivers. Plantations of this subspecies have been formed near Kano recently, but the climate here is dry tropical rather than subdesert.

Acacia senegal (L.) Willd. (Gum arabic)

This is one of the few trees than can be cultivated economically in the subdesert zone relying on rainfall alone for its soil moisture. It is indigenous from northwestern India, across north Africa to Senegal. No more than a bush in areas of just over 100 millimetres of rainfall, it attains a height of 3 to 5 metres under a rainfall of 300 to 500 millimetres. It forms open, park-like vegetation in the arid zone of Sudan, where it is an important tree economically as the source of gum arabic, for which it is extensively cultivated.

The traditional method of cultivation is as a bush-fallow crop in conjunction with farming, coppice regrowth of the gum following the agricultural phase. Tapping for gum takes place during the bush-fallow period which may last for 15 to 25 years. Shortening fallow periods, due to increasing pressure on land for agriculture, are believed to be leading to a decrease in the gum population in Sudan. At the end of the

bush-fallow period, when the trees are felled, the wood from them provides the bulk of the firewood needs of the people.

The trees have a natural life span of about 25 to 30 years. The wood is hard and heavy and is used for agricultural implements and for weavers' shuttles as well as for fuel. The main product of value is, however, the gum arabic which is tapped by wounding the stems, and is exported in large quantities for use in medicine, for the manufacture of fruit gums and in the textile industry. The value of these exports in Sudan is of the order of U.S.$15 to 20 million per year.

The tree prefers a subtropical to tropical climate with mean annual temperatures around 25 to 27°C and mean maximum temperatures up to 45°C or more. It is only marginally frost hardy and is intolerant of waterlogged conditions. Apart from these factors, it is very hardy and can survive long periods of drought once it is established. It coppices readily and seeds abundantly every year. About 7 000 to 8 000 seeds go to the kilogramme. Germination capacity is high and seeds are generally sown without pretreatment.

Much recent research has been directed toward the raising of gum stands artificially. Direct sowing of seed together with agricultural crops has been found to be successful and cheap. Hand sowing in pits of 30 centimetres cubed at a spacing of 4 × 4 metres is considered the best method on the sandy soils of western Sudan, while on the clay soils of eastern Sudan sowing in ploughed furrows 15 to 20 centimetres deep and 4 metres apart, in spots at intervals of 4 metres along the furrows, is found to be fairly satisfactory. Five to eight seeds are sown per patch. Critical experiments have shown that sowing in pits of 30 centimetres cubed dug out and the soil replaced gives slightly better results (Waheed Khan, 1966b). Planting out seedlings raised in soil blocks has given a higher degree of success but is much more expensive, owing to the nursery costs involved.

As *Acacia senegal* plantations are dependent on rainfall for their soil moisture in a very dry climate, well-planned soil working and intensive weeding to catch and conserve as much moisture as possible are essential for the successful establishment of plantations. Removal of all competing vegetation and thinning out the seedlings to one per patch are important operations. The seedlings stand up well to mechanical weeding (disc harrowing), and for this accurate alignment of the planting spots is necessary.

Methods of enriching the various types of mixed *Acacia* savanna on the clay plains in Sudan (e.g. *A. mellifera* wooded steppe, *A. seyal — Balanites* savanna and *Anogeissus — Combretum hartmannianum* savanna woodland) by introducing *A. senegal* are being intensively investigated but, so far, any extensive regeneration of *A. senegal* has been confined to those areas where it is already present, on the assumption that ecological conditions are likely to be more favourable (Blunt, 1926; Bosshard, 1966a; FAO, 1969b; Waheed Khan, 1966b).

Azadirachta indica A. Juss. (Neem)

This species has been tried in this climatic type in a number of countries but has not succeeded well under such dry conditions. Its minimum water requirements are about 450 millimetres. It stands heat well and has been successful in irrigated plantations and as an isolated irrigated tree. It tolerates a period of drought of several months and is recommended for the arid zone where irrigation is available, or for canal plantations or on river silts with annual flooding. (For further notes see under Climatic type 3.)

Conocarpus lancifolius Engler

Considerable interest is being shown in this tree in Sudan, where it is regarded as one of the more promising species for subdesert areas (under 400 millimetres of rainfall), in conditions where groundwater is available near the surface. It has done well in irrigated plantations where it grows rapidly to timber size, having a straight bole and a narrow crown, and it is now recommended for planting in dry areas in irrigated plantations, on alluvial soils that are flooded annually and on any soil with a high water table. It withstands drought conditions for several months when irrigation fails. In Somaliland, where it is native, it is recommended for planting along the coastal plain on sites where fresh or brackish water is near the surface, and on the banks of watercourses in the northern foothills of the main escarpment.

The wood is light in colour and of medium to heavy density (8.1 kilogrammes per cubic metre or 51 lbs per cubic foot). It is a good ship-

building timber, wood from Somaliland being used by the Arabs for building their dhows. It has a long life in salt water. It has an interlocked grain which gives it strength but makes it difficult to plane. It cuts and drills cleanly and is a good general-purpose timber used for house building, flooring and furniture. In the round it is used for posts, poles, etc. The tree is evergreen and the foliage is a good fodder.

The tree seeds prolifically at an early age and the seed, which is small (2 millimetres long) and light (about 1 700 000 per kilogramme), has a germination capacity of about 25 percent. When sown it should either be left uncovered or covered very thinly, not more than 1 millimetre deep. It can be raised either by broadcasting in nursery beds and planting out as striplings when one year old (Somaliland practice), or by sowing in polythene pots, six to seven seeds per pot. Germination and growth are best in full sunlight. Planting out is done when fairly small in irrigated areas (Sudan). Intensive weeding and regular watering or irrigation are essential in the early stages. Spacing is 3 × 3 metres to 5 × 5 metres according to site. The tree is a strong light demander. Young trees often fork, and unwanted leaders have to be cut back. It is attractive to browsing animals, and complete protection is necessary if plantations are to survive. Early height growth of over 2.5 metres per year has been achieved in irrigated plantations though 1 to 1.75 metres per year is more typical in early years. Mean annual increment was calculated to be about 21 cubic metres per hectare per year. It grows more slowly in unirrigated conditions and in many cases may not reach usable timber size in a reasonable time. For further information see Boaler, 1959; Bosshard and Wendorff, 1966; and Bosshard, 1966a.

Dalbergia sissoo ROXB.

The minimum water requirements of this species are said to be about 700 millimetres. It cannot be grown in the subdesert zone, unless in irrigated plantations, or on sandy or silty soils with a high water table, or along rivers with annual flooding. It cannot stand heavy or waterlogged soils. It has given promising results in the irrigated Khartoum greenbelt where it will stand an interruption of irrigation of three or four months in the hottest season. Tree form is poor and yields of fuel and poles are far inferior to some of the eucalypts. It is only worth considering where timber-sized trees can be grown, as it is an excellent timber for many purposes.

Eucalyptus SPP.

In the subdesert zone, even the most drought-resistant species of *Eucalyptus* such as *E. microtheca* do not grow sufficiently well to be worth planting unless they can be irrigated or unless planted on sites with subsoil water. Where they have to depend entirely on the natural rainfall of the locality, they only begin to be economic in the moister zones with a rainfall of at least 600 to 1 000 millimetres and usually more.

The following species can sometimes be grown successfully in the subdesert zone and are briefly mentioned here. They are dealt with more fully under moister climates, where they can be grown without irrigation.

Eucalyptus camaldulensis Dehn. — Syn. *E. rostrata* Schlecht. (River red gum, Murray red gum)

This, the most widely distributed of all eucalypts in Australia, varies widely according to provenance. In its natural habitat it is found along watercourses, on flood plains and on alluvial flats with a high water table. It stands a variety of climates including in some cases a high degree of aridity. It grows on sandy and silty soils with permanent subsoil moisture. It tolerates seasonal flooding but cannot stand permanent or long-term water-logging. The best growth is found on deep silts.

As might be expected, it does very well in irrigated plantations and is, in fact, the fastest growing eucalypt under sewage irrigation in the Khartoum greenbelt of Sudan. Three-year-old trees average 10 to 12 metres in height and yield approximately 63 cubic metres per hectare at that age. The form of the trees, which are of a Moroccan provenance, is not good and other provenances are being tried. In northern Nigeria it has been grown successfully on well-drained sands with a high water table close to Lake Chad where heights of up to 14 metres were attained in three years. The annual rainfall in this area is very low and uncertain, and the trees had to be watered during the first year. *E. camaldulensis* is planted fairly extensively in other cli-

matic types and for further information see under Dry tropical and Semihumid tropical climates.

Eucalyptus microtheca F. v. Muell.

This species is native to northern Australia, growing on heavy black clays which are waterlogged in wet weather and baked hard and fissured in dry. It is the most drought resistant of all the eucalypts tried in Sudan and withstands high temperatures, periodic drought and seasonal flooding on the heavy clays and black cotton soils of the Sudan Gezira, where it is extensively planted in irrigated plantations. It is found to require the equivalent in irrigation of at least 600 to 700 millimetres of rain, and will tolerate a period of four to six months' drought. It is less tolerant on the poorer soils of the Khartoum greenbelt where, in the worst places, it began to suffer after two months without irrigation, though a tolerance of three and a half to four months of drought was more normal in the better areas. It is recommended for planting in irrigated plantations on heavy cracking clays even if irrigation is not regular, and also for plantations on river silts with annual flooding even where the flooding is rather irregular. Where irrigation or seasonal flooding are absent, this species, in spite of its high resistance to drought, is not suitable for planting in the subdesert zone.

FIGURE 9. Coppice crop, and one residual tree from previous rotation, of *Eucalyptus microtheca* under irrigation in the Gezira, Sudan.

(*Courtesy* M.A. Waheed Khan)

TABLE 6. — *Eucalyptus microtheca*: SUMMARY OF VOLUME CALCULATIONS [1]

Number of stems/tree	Number of trees	Total trees	Total volume	Total volume	Volume per tree	Ratio [2]	Volume per stem
		Percentage	*Cubic feet*	*Percentage*	*Cubic feet*		*Cubic feet*
1	314	27.8	534.10	18.10	1.70	1.00	1.70
2	497	43.9	1 314.00	44.50	2.64	1.55	1.32
3	252	22.3	814.25	27.60	3.23	1.90	1.08
4	54	4.8	229.96	7.80	4.26	2.51	1.06
5	13	1.1	57.42	1.90	4.42	2.60	0.88
6 [3]	1	0.1	0.49	0.02	0.49	0.29	0.08
Total	1 131	100.0	2 950.22	99.92			
Average					2.61		1.25

[1] Waheed Khan, 1966d.
[2] Ratio of volume per tree/volume of one-stemmed tree.
[3] Figures refer to data from inadequate sample.

It is a rather crooked tree, growing to about 14 metres in height, and has a heavy, hard, dark heartwood that is resistant to termites. It is mostly grown for fuel but is also useful for low-grade posts and poles. It coppices readily and the coppice crop is of much better form than the original seedling crop. Straightness might well be improved by trials of different provenances from Australia.

Single tree volume data from 1 131 trees felled in various plantations in the Gezira varying in age from 8½ to 11½ years are given in Table 6.

It is normally regenerated by direct sowing in polythene pots and planting out after six months in the nursery (Waheed Khan, 1966a).

Eucalyptus tereticornis Sm. — Syn. *E. umbellata* (Gaertn.) Domin. (Forest red gum)

Minimum water requirements are about 500 millimetres per year, therefore it can be grown in the subdesert only where there is subsoil moisture or irrigation. It grows well on good, deep and well-drained soils such as sandy loams, river terraces and rich alluvial soils. In Sudan it is grown in irrigated plantations, canal plantations and gardens. Australian provenances tried have proven less drought resistant than either the Mysore, India, provenance or *E. microtheca*, and inferior in form to *E. camaldulensis*. The poles split less than those of *E. camaldulensis* when grown in irrigated plantations. Being a species of wide natural distribution, the provenances vary considerably. It is of greater interest for planting in moister climates.

A particularly good provenance or hybrid of *E. tereticornis* from Mysore, India, generally known as "Mysore gum" or "Mysore hybrid," is promising in the savanna. It is planted in India in climates with 500 to 750 millimetres of rainfall, stands up to six months of drought, and is grown on a variety of soils, but needs fertile conditions for good results.

In the subdesert savanna zone, "Mysore gum" has been grown with irrigation on suitable soils in the Khartoum greenbelt and has been found to be definitely more drought resistant than *E. tereticornis* of Australian provenance but less so than *E. microtheca*. It is fast growing under favourable conditions; the best plot in the greenbelt grew 3.2 metres per year and, though variable, has, in general, better form than Australian *E. tereticornis*. "Mysore gum" is recommended in Sudan for irrigated plantations on clays and silts, particularly where irrigation is likely to be interrupted by periods of drought.

Prosopis chilensis (MOLINA) STÜNTZ (MESQÙITE)

This species was formerly known as *P. juliflora* (Swartz) DC. but has now been named as a separate, though very similar species, *P. chilensis*. It has been introduced widely in arid areas of the Near East and north Africa, though actual areas of planting are limited.

It is a large bush or small tree, very thorny. It is highly drought resistant and it tolerates a variety of soils including very poor dry shifting sands. It has considerable sand stabilizing capacity and is useful for this purpose. It is important as a pioneer species in very arid areas and provides fuel and fodder (from the pods) in the arid zone. In Sudan it has given quite promising results in the 140- to 250-millimetre rainfall zones on soils with a relatively good water-holding capacity and also on some salty soils on the Red Sea coast. A 16-year-old plantation clear felled at Khartoum North yielded 25 cubic metres of fuel per hectare, a mean annual increment of 1.6 cubic metres per hectare per year, but this could have been greatly increased if the area had been fully protected against cutting and grazing (Wunder, 1966a). Two distinct strains were noted in this plantation, differing in form, height and bark characters.

It is easy to establish by broadcast sowing of pretreated seed, followed by light mechanical tilling, or by planting container stock. In Sudan, establishment by means of potted plants gave 96 percent success and an average height growth of 85 centimetres four months after planting.

It regenerates naturally, once established, and can become a serious weed if grown on sites that are too good, e.g. in moister zones, on better soils or in irrigated plantations.

Climatic type 3. Dry tropical

Though moister than the semidesert, this climatic type still has a long and severe dry season of six to eight months, variable and unreliable rainfall and high temperatures in the hot season which severely restrict the possibilities of economic afforestation. Rainfall is usually 400 to

1 000 millimetres per year, frequently below 800 millimetres. In general, a higher rainfall is required to produce a similar vegetation type in the northern than the southern hemisphere, in order to compensate for the desiccating winds from the Sahara.

Given the necessary groundwater conditions as described for the various species under the subdesert climate, any of those species will grow as well or better in the dry tropical climate, and the range of possible species is somewhat extended. Where this type of climate is found at higher elevations, e.g. up to 1 400 metres in Zambia or Rhodesia, the hot weather drought conditions are somewhat moderated and this allows the use of more demanding species.

The following species have either been grown successfully or have shown promise in species trials in this climatic zone.

Anacardium occidentale L. (Cashew nut)

Native of tropical America and the West Indies, it was introduced into Africa several centuries ago and has become naturalized in many places. It is widely planted, mainly in west Africa, for soil conservation purposes and for windbreaks, and in east Africa more usually for the production of nuts.

It grows well on sandy soils and on latosols and will tolerate a high degree of laterization, but it does poorly on heavy clay soils. It is commonly found in coastal areas.

There is a good account of the method of forming plantations in Senegal by Giffard, 1966. The site must be completely free from all shrubby and woody growth and stumps. Clearing and site preparation are done with a heavy disc plough such as the 1 500-kilogramme " Rome " plough. Where possible the plantations are raised with taungya, using millet or groundnuts as the agricultural crop. The cashew is introduced by direct sowing fresh nuts, two per planting spot, several weeks before the rains are expected. This early sowing is considered to be vital for success, as it enables the plants to develop sufficiently good root systems to survive subsequent breaks in the rains during the first year.

Since the primary purpose of the plantations in Senegal is soil protection and windbreaks, a close spacing of 3 metres in each direction is used.

Where grown primarily for fruit and nuts, the tree requires full light and much more room, therefore wider spacings are necessary since it will develop a crown 8 metres in diameter. Six- to ten-metre spacing in both directions is common. In Madras for instance, the spacing used in the commercial cashew nut plantations is 10 metres or about 100 per hectare. This, however, is in a moister climate, with 1 200-1 500 millimetres of rain.

In the drier savanna areas with a dry tropical climate, complete elimination of weed competition for available soil moisture is necessary and, in the case of taungya, close supervision may be necessary to see that the cultivators do not allow the agricultural crops to compete with the cashew plants.

Normally, with good soil preparation and proper weeding, complete stocking is achieved. There are, however, some dangers to be avoided. Termites can be troublesome, especially in the heavier soils with a high humus content. Near the sea, crabs sometimes completely destroy plantations by removal of the nuts after sowing, or by nipping off the young plants. Serious damage is also caused by palm rats, monkeys, hares and hornbills. Termite damage can be controlled by application of insecticides but no satisfactory method of controlling crab damage has so far been found and planting on littoral dunes has had to be abandoned. Palm rats are the most serious of the other pests and attempts at controlling them by means of an anticoagulant poison (Turagil) have shown initial success.

The uses of *Anacardium occidentale* are primarily (in west Africa particularly) protection of the soil and provision of shelter from the wind. Valuable secondary benefits are the production of cashew nuts and cashew apples which bring in considerable revenue. The wood is useless for timber and although sometimes used for fuel, it is not much liked as the bark contains oleoresins which cause sparking with attendant risks of fire. Where the tree is grown primarily for its nuts, higher rainfall areas are preferred. Trees start bearing when about 5 years old and continue production up to 30 to 40 years of age. One hectare of well-grown middle-aged cashew plantation will, under favourable conditions, yield up to 2 800 kilogrammes, giving about 675 kilogrammes per hectare of kernels. Considerable improvement in nut quality and yield has been achieved by selection and breeding.

Azadirachta indica A. Juss. (Neem)

Native of the drier parts of India and Burma, this tree is one of the most useful and widely planted trees in the dry tropical climatic type. It also grows well in the semihumid tropical climate, but is less used there, as other more useful species are available. It is not suited to the subdesert which is too dry for it, except with irrigation. It is evergreen and is commonly grown as a village tree, as it gives excellent shade and provides firewood from pollarding or coppicing. It is widely planted for poles and fuel and yields good timber useful for furniture.

Figure 10. *Azadirachta indica*, seven to eight years old, 25 to 30 feet (7 to 10 metres) high, and spaced 15 × 15 feet (4.6 × 4.6 metres), ready for coppicing for fuelwood production north of Kano, Nigeria.

(*Courtesy* R.L. Willan)

It requires at least 450 millimetres of rainfall but does most satisfactorily where the rainfall is 600 millimetres or more. If groundwater is present at a depth of not more than 18 metres at the height of the dry season, it will grow satisfactorily under lower rainfall conditions. It does well in irrigated plantations but grows poorly if waterlogged. Given adequate groundwater, it stands atmospheric drought and high temperatures well, though in Nigeria some drying of the leaves in the hot dry winds has been reported.

It is tolerant of a wide range of soil conditions, provided the soils are reasonably deep and not too acid. The minimum pH should not be below 6, and a pH of 6.5 or higher is preferable. It grows on sands, silts and heavy clays including black cotton soils and even on dry stony soils. On an alluvial silt with a moist subsoil (" gerf lands ") in Sudan under a rainfall of about 600 millimetres, dominant stems in a 24-year-old plantation reached about 22 metres in height and 51 centimetres in diameter. In Nigeria it has done well in pure plantations in the 500- to 625-millimetre rainfall belt at about 300 metres elevation on freely drained soils with a water table at a depth of 18 metres during the dry season and a pH of over 6.

There have, however, been instances of plantation failures, the exact cause of which has not been determined. Both in Sudan and in northern Nigeria, in places where individual trees have grown well, plantations which started satisfactorily have checked after about two years and were mostly dead or moribund by the fourth year, and this has given the species a reputation for unreliability. Suggested causes are too acid soil or too dense stocking in relation to available moisture. Research is in progress to determine the cause of these failures.

The neem fruit is a drupe. It should be collected when fully ripe, which is usually about the month of June, and the pulp removed before sowing. The seed rapidly loses its viability and must be used fresh, i.e. within a week or two of collection. About 4 000 seeds go to the kilogramme and average germination of fresh seed is usually about 75 percent. It grows fast in the nursery in ordinary soils and is generally easy to handle.

Plantations are usually raised from one-year-old stumps or three-month-old container plants. In some areas success has been achieved with direct sowing, but generally this is less reliable. Being a strong light demander it requires adequate spacing in plantations; 2.4 × 2.4 metres, for instance, is normal in northern Nigeria when grown for poles or fuel on an eight-year rotation. If grown for timber on longer rotations, it requires regular thinning. It coppices and pollards well. The tree is variable in form, rate of growth and drought resistance, and a programme of provenance trials would be desirable.

In the Sudan zone of Nigeria which falls within the dry tropical climate, neem has hitherto been the principal species for the production of fuelwood and poles. Provisional production figures

have been worked out from measurements of over 120 plots (Gravsholt, Jackson and Ojo, 1967). Four site quality classes are recognized, the mean of all the plots being almost exactly quality class 3. Initial spacings varied from 1.8 × 1.8 metres to 3 × 3 metres, 2.4 × 2.4 metres being by far the commonest. Data are given for plantation ages of three to nine years by single years and volumes per unit area for minimum utilizable diameters of 2.4, 3.2 and 4.0 centimetres, separately for first rotation crops and coppice crops. The following figures, derived from the various tables, illustrate the range of production rates to be expected.

The very rapid fall in production as the site quality decreases is noteworthy; (e.g. a drop in height growth of 23 percent from quality class 2 to 3 results in a drop in volume production of 53 percent). It should be noted that these figures are for fully stocked crops. These are the exception under savanna conditions, so that in applying the tables, allowance must be made for incomplete stocking. Crops established at 1.8 × 1.8 metres spacing produced from 12 percent (quality class 1) to 17 percent (quality class 2) more in volume per unit area than crops planted at 2.4 × 2.4 metres at eight years of age.

TABLE 7. — GROWTH AND PRODUCTION OF EIGHT-YEAR-OLD *Azadirachta indica* (NEEM) PLANTATIONS AT SPACINGS OF 2.4 × 2.4 METRES (8 × 8 FEET)

Site quality class	Crop	Average height		Volume of usable wood down to 3.3 centimetres (1.3 inches) top diameter		Mean annual increment	
		Feet	*Metres*	*Cubic feet/acre*	*Cubic metres/hectare*	*Cubic feet/acre/year*	*Cubic metres/hectare/year*
1	First rotation	37	11.3	2 150	150.0	270	18.7
	Coppice	37	11.3	2 100	147.0	263	18.4
2	First rotation	30	9.1	1 300	91.0	163	11.4
	Coppice	30	9.1	1 250	87.5	156	10.9
3	First rotation	23	7.0	700	49.0	87	6.1
	Coppice	23	7.0	650	46.5	81	5.8
4	First rotation	16	4.9	250	17.5	31	2.2
	Coppice	16	4.9	250	17.5	31	2.2

Callitris SPP.

Trials of several species of this genus have been made in various countries under savanna conditions. Most of these have been in the moister climatic zones, notably the semihumid tropical climate, in areas having a rainfall over 1 000 millimetres per year. A few species, however, have grown sufficiently well in localities with a rainfall under 1 000 millimetres to be worth mentioning, namely *C. calcarata* (Syn. *C. endlicheri*), *C. glauca* (Syn. *C. huegelii*) and *C. intratropica*. For further particulars see under Climatic type 4, semihumid tropical.

Cassia siamea LAM. — SYN. *Cassia florida* VAHL.

One of the oldest and most extensively planted exotics in the past, it is only successful on unusually favourable, well-drained soils in this zone, in localities where there is no severe moisture deficit during the dry weather. Where conditions are less favourable, it often starts well but ceases to grow after the first two or three years. Of value only for fuel in this zone, it is now hardly planted at all as better species for fuel and pole plantations, notably some of the drought-resistant eucalypts, are taking its place. For further particulars see under Climatic type 4, semihumid tropical.

Dalbergia sissoo ROXB.

This species was mentioned as sometimes growing satisfactorily in the subdesert climate where soil moisture was available during the dry season. It has been tried widely in the dry tropical climatic type in west Africa (Ghana, northern Nigeria, north Cameroon and Togo) over half a century, but on the whole it cannot be said to have been successful. In northern Nigeria the best growth was achieved on sandy-loam soil with exceptionally favourable soil moisture and fertility; three years after planting on this site the mean height was 4.6 metres but survival was only 33 percent. On less favourable sites, including gravelly lateritic soils, mean heights of 2 to 3 metres may be reached in two years,

but experience shows that the fast initial growth is not maintained. It is capable of surviving well on dry sandy soils, but growth is very poor and only the best trees reached 3.0 metres after five years of growth. Being a tree of river beds and alluvial flats bordering rivers, it needs fresh moving subsoil moisture and cannot stand badly drained soils and stagnant soil moisture conditions. In Sudan it is showing some promise on silty soils with a rainfall of 500 millimetres. In Ghana it has been planted since 1943 in savanna woodland. Under favourable conditions the height may reach 3 to 3.7 metres in the first year and 9 to 11 metres in five years, but this is exceptional.

Stem form is generally poor, and even under dense canopy, dead branches tend to persist. Establishment is by planting stumped seedlings or sometimes by striplings. Trees start bearing fertile seed from their fourth or fifth year. Root suckers appear abundantly at three to four years of age, but die back if not severed from the parent tree. This suckering capacity is useful on eroding sites. The tree is very susceptible to infestation by the "mistletoe" *Tapinanthus dodoneifolius* and to various fungal diseases and defoliators.

The tree produces fuel of excellent quality, and also short but very strong poles. The sapwood is very susceptible to boring insects, but the heartwood is durable. Under savanna conditions it seems unlikely to produce anything more than fuel and small poles.

Eucalyptus SPP.

Over 100 different species of *Eucalyptus* have been tried in experimental plantings in different countries in the various savanna types. Of these only some ten to twelve show sufficient promise to be worth further investigation or immediate planting on a commercial scale.

Site requirements

Experience to date indicates that all the species that have shown any promise prefer deep, freely drained sandy to sandy clay soils with an unimpeded rooting depth of at least 2 to 2.5 metres and preferably more. The selection of such sites is done (in Zambia for instance) by initial extensive surveys at an intensity of one soil pit per 36 hectares and followed in suitable areas by more intensive surveys of one pit per 9.2 hectares (Allan, 1967a).

Many eucalypt species have only been tested for a short time and the assessment of the site requirements of each species on the evidence of a few years' growth may be very uncertain. A lengthy period of trial is required to demonstrate ability to sustain satisfactory rates of growth on freely drained soils with a long and severe dry season. It has been found that some species, which show good survival and early growth on such sites, may later suffer a serious check in growth rate or even widespread death from drought, particularly if they grow on heavier and moister soils in their country of origin. Several measures may be useful in mitigating the effects of summer drought on growth and survival. They are:

(*a*) the provision of ample rooting depth, in which the trees can tap moisture from as big a volume of soil as possible;
(*b*) the adoption of clean weeding to ensure that there is no competition for available soil moisture from other vegetation;
(*c*) the use of wide initial spacing or early thinning to ensure that there is sufficient moisture per tree in the dry season to maintain adequate health and growth when the trees have grown big.

It has been observed in northern Nigeria (Kemp, 1969, 1970) that all the species that have so far been successful have come from areas of predominantly summer rainfall.

Present status and recommendations

On the basis of present knowledge there are only three or four species which are recommended for extensive planting, and five or six more which deserve more extensive and prolonged trial. In addition to these it is possible to select a few others which may be of value on the more difficult sites. This applies particularly to some species from dry areas which are strongly lignotuberous.

Recommendations for large-scale planting of any eucalypt species must take into account the utility of the produce. For use as fuel there is rarely any doubt about its suitability. For posts and poles, not only must the produce be reasonably straight but its durability is important. Some doubts have been cast on the durability of fast-grown poles from plantations. South

African experience has confirmed this and has shown that preservative treatment of all materials used as poles or posts is desirable. For timber, the earlier difficulties of warping and twisting in converted material now seem less serious, as they can largely be overcome by appropriate seasoning and reconditioning treatments. Early tests of locally grown material are highly desirable (Kemp, 1969, 1970).

Eucalyptus camaldulensis Dehn. — Syn. *E. rostrata* Schlecht. (River red gum, Murray red gum)

As mentioned under the previous climatic type this is the fastest growing species of eucalypt in Sudan if it is irrigated. In Nigeria the most successful plantations so far have been at Afaka in the semihumid tropical climatic type. In the dry tropical climate (the " Sudan " vegetation zone) in Nigeria there are no fully stocked plantations so far, the main cause being severe termite attack. Growth of individual trees is, however, rapid and on some sites the fastest trees have reached 13.7 metres in six years. Apart from termite damage, no serious pests or diseases have been observed, though experience in Zambia suggests that there may be a possibility of boron deficiency affecting certain provenances on some sites. The species is tolerant of a wide range of site conditions, as is to be expected from its very extensive natural distribution in Australia, and furthermore it exhibits a great range of individual tree variation in growth rates, stem form, crown density, etc. Its stem form is poor in general, though there are individual exceptions, and the crowns are usually light and open, insufficiently dense to suppress grass. But its variability in these characteristics, as well as in the rate of growth, offer great possibilities for improvement by selection of provenance and of individual parent trees. Intensive provenance trials have been established in a number of countries, e.g. Nigeria, Congo, Sudan, Rhodesia, Zambia, which should provide information for the selection of better strains. Already certain provenances are showing distinct superiority in several countries, notably S. 6845 (Lake Albacutya, Victoria, 350 millimetres of rainfall, well distributed), S. 6953 (Petford, Queensland, 720 millimetres of summer rainfall with winter drought) and S. 6869 (Katherine, Northern Territory, 960 millimetres of summer rainfall, with severe winter drought) (Lacaze, 1970). For example, in a provenance trial at Afaka, Nigeria (semihumid tropical climate), the best provenance (Petford) reached an average height of 17.8 metres and a total average volume of 83 cubic metres/hectare at the age of 4.8 years. The only provenance so far found successful in the dry tropical climate of Nigeria (apart from areas with subsoil moisture) is that from Katherine (Allan, 1973b).

FIGURE 11. Petford provenance of *Eucalyptus camaldulensis*, four years old, at Afaka, Nigeria.

(*Courtesy* J.K. Jackson)

Eucalyptus citriodora Hook (Lemon-scented gum)

This species is better suited to moister climates, though in its natural habitat it extends into areas with only 600 millimetres of rainfall. Both on deep dry sands and on poorly drained soils in the Sudan zone of Nigeria survival has been low and growth poor. It has done well in this zone on well-drained sandy loams with a fairly high dry-season water table of 6 metres. Hence, on account of its desirable properties of good bole form and timber quality it has been recommended for growth trials on the best sites in the Sudan zone of Nigeria using provenances from the more northerly and drier parts of its natural range in Queensland (Australia).

For further information on this species see under Climatic type 4, semihumid tropical.

Eucalyptus microtheca F.v. Muell. (Flooded box)

This species has already been mentioned as suitable for the subdesert climatic type, where groundwater or irrigation is available. It is more drought resistant than *E. camaldulensis*, and suffers less from termite damage. It has consistently achieved the highest rate of survival of any eucalypt in the Sudan vegetation zone of northern Nigeria. Initial growth is moderately fast, 0.6 to 1.2 metres per year over the first two years on most sites, but 1.5 to 1.8 metres on more favourable sites. Early growth is unimpressive owing to the poor stem form.

In terms of survival, this is the most successful species of *Eucalyptus* so far tried on average-to-poor sites in the Sudan zone of Nigeria. It can safely be relied upon to provide some sort of cover, but seems unlikely to produce anything better than firewood and poor quality small poles, except possibly under irrigation. It is not recommended for planting in areas where it is possible to grow better species successfully. Its value lies in its reliability and its capability to survive in conditions of relative drought and of termite infestation, where most other species would fail. Attempts are being made to improve the species through provenance selection.

Eucalyptus tereticornis Sm. — Syn. *E. umbellata* (Gaertn.) Domin. (Forest red gum)

This species does rather better in the semihumid tropical climatic type, under which it is further discussed. It has, however, been tried fairly extensively and (provided there is subsoil moisture) with some success in the dry tropical climate.

In the Sudan zone of northern Nigeria it has, like *E. camaldulensis*, suffered severely from termite attack and survival has been reduced to 20 to 30 percent in some cases. Early height growth is usually quite good, even on deep upland sandy sites, though in general it grows slightly slower than *E. camaldulensis* on similar sites in this area. Typical early mean height growth is 0.6 to 0.9 metres per year, though in the first two years mean heights of 3.0 to 4.5 metres are sometimes attained. The seed sources used were mostly from New South Wales (Australia) but a provenance from New Guinea which was planted on only one site gave especially promising results, with a mean annual height increment over the first three years of 1.2 to 1.5 metres, and after six years the tallest trees had reached 10.7 to 12.2 metres in height and 9.5 to 10.5 centimetres in diameter at breast height. The stem form of this provenance is excellent and much superior to the New South Wales source.

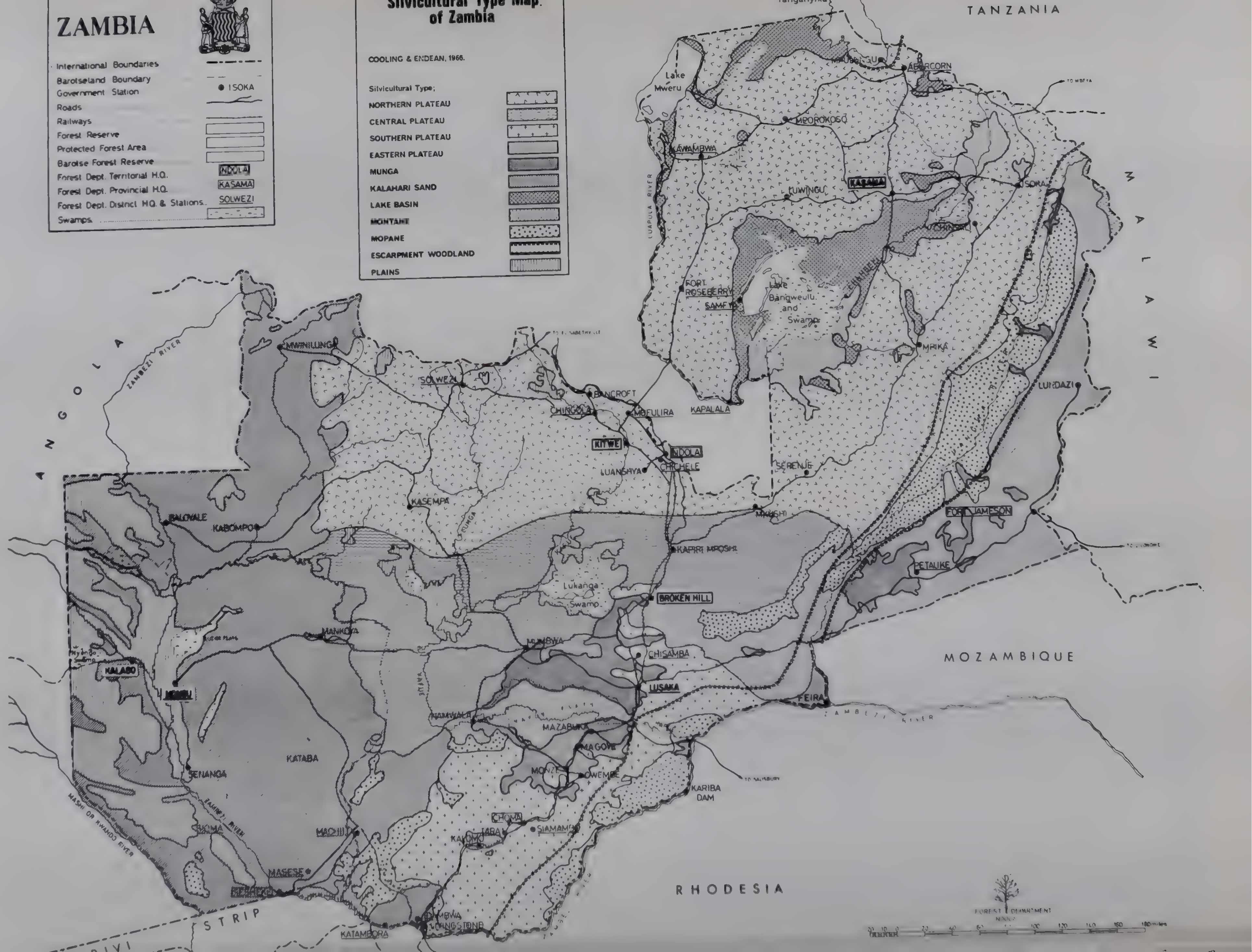
In Zambia trials of *E. tereticornis* have been carried out under similar rainfall conditions at three or four sites but at higher elevations — 900 to 1 400 metres. Such localities have a slightly cooler climate and a less rigorous dry season. Seed sources were mostly from Queensland with a few from Zanzibar and one from Rhodesia. The growth of all provenances was faster than that reported for the Sudan zone of Nigeria, though the figures are not strictly comparable. The Zambian figures are "top heights," defined as the average height of the 10 percent of the crop trees having the largest diameters. Even so, the range of annual height increments was from 2.2 to 4.3 metres for ages from one and a half to six years approximately (Cooling and Endean, 1966). At that stage it was not possible to establish any marked differences between provenances.

E. tereticornis has been planted quite extensively on the "gerf lands" (alluvial silt with a moist subsoil) along the Blue Nile in the 500- to 800-millimetre rainfall zone, where it has shown excellent growth and good form. At 14 years old, heights vary from 24.7 metres for first quality sites to 17.4 metres for third quality sites with corresponding breast height diameters of 35.6 and 18.6 centimetres respectively. It is hoped to use the product for telegraph and possibly transmission poles after impregnation.

For further information on this species see under Climatic type 4, semihumid tropical.

Climatic type 4. Semihumid tropical

In this type there are usually four to five dry months in the year. Rainfall is usually between 1 000 and 1 500 millimetres but may be as low as 800 millimetres. Growth conditions within this type are variable, not only on account of the range of rainfall included but also on account of variations in elevation which affect the temperature and moisture regimes. Soil variations


ZAMBIA
International Boundaries
Barotseland Boundary
Government Station
ISOKA
Roads
Railways
Forest Reserve
Protected Forest Area
Barotse Forest Reserve
Forest Dept. Territorial H.Q.
NDOLA
Forest Dept. Provincial H.Q.
KASAMA
Forest Dept. District H.Q. & Stations.
SOLWEZI
Swamps
Silvicultural Type Map of Zambia
COOLING & ENDEAN, 1966.
Silvicultural Type;
NORTHERN PLATEAU
CENTRAL PLATEAU
SOUTHERN PLATEAU
EASTERN PLATEAU
MUNGA
KALAHARI SAND
LAKE BASIN
MONTANE
MOPANE
ESCARPMENT WOODLAND
PLAINS
TANZANIA
MALAWI
MOZAMBIQUE
RHODESIA
ANGOLA
STRIP
Lake Mweru
ABERCORN
MPOROKOSO
KAWAMBWA
KASAMA
LUWINGU
ISOKA
CHINSALI
FORT ROSEBERRY
SAMFYA
Lake Bangweulu and Swamp
CHIHBEBI
MPIKA
LUNDAZI
FORT JAMESON
PETAUKE
SERENJE
MKUSHI
KAPALALA
LUAPULA RIVER
MWINILUNGA
SOLWEZI
BANCROFT
CHINGOLA
MUFULIRA
KITWE
NDOLA
CHICHELE
LUANSHYA
KASEMPA
KABOMPO
BALOVALE
KAPIRI MPOSHI
BROKEN HILL
Lukanga Swamp
MANKOYA
MUMBWA
CHISAMBA
LUSAKA
FEIRA
ZAMBEZI RIVER
KALABO
MONGU
KATABA
NAMWALA
KAFUE
MAZABUKA
MAGOYE
MONZE
GWEMBE
KARIBA DAM
CHOMA
SIAMAMBO
SENANGA
MACHILI
MASESE
SESHEKE
KATAMBORA
LIVINGSTONE
MASHI OR KWANDO RIVER
FOREST DEPARTMENT
TO SALISBURY

also have a significant effect on what can or cannot be grown economically.

Both the northern Guinea and the southern Guinea vegetation zones of Nigeria occur within this climatic type. In the southern Guinea zone, the rainy season is more prolonged and the dry season less severe than the northern Guinea zone. The Jos Plateau of northern Nigeria is regarded as a subdivision of the northern Guinea zone. It has the same rainfall and humidity regime as Kaduna, which is a typical northern Guinea zone station, but is about 700 metres higher and its climate is therefore slightly cooler and less severe (Kemp, 1969, 1970).

Other extensive savanna areas in this climatic type are to be found in Zambia, in the northern plateau vegetation zone (Figure 12) at 1 200 to 1 350 metres' elevation (Cooling and Endean, 1966) as well as in south and southwest Sudan, and parts of Uganda, Kenya, Tanzania, Malawi, Rhodesia, etc.

Acrocarpus fraxinifolius WIGHT

This species occurs in high rainfall areas at medium elevation in India. It is best adapted to cool highland areas, but may be suitable for planting near the upper elevation limits of the savanna, especially in Climatic type 5, humid tropical, under which further information will be found.

In the semihumid tropical climate it merits mention as a species which "flatters to deceive." In a number of countries rapid initial height growth for several years has been followed by stagnation and high mortality. In Tanzania trial plots showed early promise on savanna woodland sites at about 1 200 metres' elevation, with a rainfall of 1 000 millimetres, but five years of satisfactory growth were followed by widespread death from drought (Commonwealth Forestry Institute, 1966). At Afaka in Nigeria, with 1 270 millimetres of rainfall on a well-drained sandy soil, survival was high and mean height had reached 6.1 metres in four years, after which growth stagnated and heavy casualties occurred.

On higher and moister sites within the savanna satisfactory growth and survival may be obtained over a longer period. In Zambia there have been a number of trials in moister savanna conditions. One of the oldest on a northern plateau site, at about 1 300 metres' elevation, reached a "top height" of 26 metres in 23 years, but much faster annual height increment has been reported from more recent plantings, where top height increments of 1.3 to 3.0 metres per year were achieved for ages between two and a half and seven and three quarter years.

In Uganda it has shown promise on termite-infested sites in the wetter parts of this climatic type, again at comparatively high elevation. Survival was good.

Araucaria cunninghamii SWEET (HOOP PINE)

The attractions of this species are its excellent timber and pulping properties combined with rapid growth and almost perfect bole form. That it has not been planted more widely in the past has been largely due to difficulties in seed supply. The seeds are short-lived, though less so in this species than in most other Araucarias, but these difficulties can now be overcome by rapid air transport and the use of low-temperature containers.

It has some disadvantages as a plantation tree. It is slow growing in the nursery and during the first four or five years after planting out, which makes it rather expensive to establish. Costs can, however, be reduced to some extent by careful attention to the special details of nursery and plantation practice which have been summarized by Ntima, 1968.

Araucaria cunninghamii has a wide altitudinal and latitudinal range, from Papua, New Guinea, at about 8°S latitude where it is found from sea level to 2 400 metres' elevation, throughout the length of Queensland into New South Wales to about 33°S latitude. It is to be expected, therefore, that there must be marked and important altitudinal and latitudinal provenance differences. These have hardly been investigated at all as far as planting in Africa is concerned, the only suggestion being that, for planting in Nigeria, seed should be obtained from the more northerly part of its range in Australia (Kemp, 1969, 1970). The Papuan strains are reported to be different in appearance from the Australian strains and, of course, they will be more tropical, especially those from low elevations.

As regards rate of growth, yield tables have been made in Queensland, where the species has been grown in plantations for many years. For instance a 55-year-old plantation with a site index of 26 metres (85 feet)[1] is expected to

[1] Dominant height at 25 years of age.

produce on an average a total mean annual increment (including thinnings) of 15.2 cubic metres/hectare/year. Of this 15.4 percent is pulpwood and 84.6 percent timber, which is a remarkably high proportion of timber considering that all thinnings are included (Hawkins and Muir, 1968).

It has been grown as an exotic in Mauritius for over 20 years and provisional yield tables have been made up to 25 years based on over 400 hectares of plantations. On site quality 1 where the average dominant height is 16.7 metres at age 25 years, the current and mean annual increments were 41 cubic metres/hectare/year and 18 cubic metres/hectare/year respectively. The corresponding figures for site quality 2 were 14 metres dominant height, current annual increment 31 cubic metres/hectare/year and mean annual increment 15 cubic metres/hectare/year. It will be seen that the mean annual increment is rapidly increasing at that age (Ntima, 1968).

On the African mainland, there is so far relatively little information on its performance as most trials are too young to produce reliable indications of later rates of production. In Nigeria, six-year-old plantations on the Jos Plateau at 1 220 metres' elevation had reached 3.6 metres' mean height. The dominants averaged 5.2 metres. Mean diameter was 5.5 centimetres and dominant diameter 7.5 centimetres. The plantations had grown slowly for the first four years and were just gathering speed. The average rainfall is 1 400 millimetres but with a severe dry season (Kemp, 1969, 1970). There is a considerable amount of evidence that early growth both in the nursery and in plantations can be accelerated by nitrogen manuring and by elimination of grass by clean cultivation.

Though requiring a high average rainfall for good growth it is very resistant to periods of drought of up to three or four months, and it does not suffer from the dry harmattan wind.

Details of seed collection and storage and of nursery work as carried out in Australia and Papua are given by Ntima, 1968. The practice is to sow the seed in drills in beds, prune the long tap roots by undercutting at a depth of 15 to 18 centimetres below ground level and transfer the plants to tubes when about 15 to 23 centimetres high, at least five months before planting out. In northern Nigeria, however, seeds were pregerminated in sterilized moist sand and pricked out into polythene pots as they germinated. Germination took 8 to 12 days but early growth was very slow and it takes 10 to 15 months to produce plantable seedlings (Kemp, 1969-70). Experiments are desirable to find out whether early growth can be accelerated by using potting soils that are richer in nitrogen or whether the slow growth is due to mycorrhizal deficiency.

In plantations clean cultivation for up to five years may be necessary, but again this period might be reduced by the judicious use of nitrogenous fertilizers.

Araucaria cunninghamii is a species that is worthy of more intensive research for savanna planting. It is likely to do well in both the semihumid tropical and the humid tropical climates. It requires richer soils than the pines and will stand heavier soils provided they are deep and well drained. It is important to find out whether provenance differences are significant both as regards latitude and altitude above sea level. In view of the difficulty and expense of obtaining seed it is a matter of high priority to determine which are the provenances best suited to the various savanna sites so that ultimately seed imports can be confined to those provenances.

Callitris spp. (Cypress pine)

Several species of this genus have been planted in Africa and have shown initially promising results. They are natives of Australia and Tasmania and come from a wide range of sites, from the hot, dry inland part of Australia to the more humid parts of the eastern and western coasts. Even within a species the range of climate can be wide, and by selection of the right provenances many savanna climates can be matched. All the species mentioned below require sandy soils or sandy loams to loams, which must be well drained.

Most species have inherently good stem form if they are closely planted, 1.8 × 1.8 metres being commonly used. They vary in the percentage of trees that have spiral grain and where grown for timber this may be an important defect. It can, however, be reduced by selection and breeding. The poles and timber are relatively resistant to white ants and the wood is ornamental, slightly aromatic and easily worked and finished.

Seeding is abundant and natural regeneration prolific in nearly all species, so that once a

plantation is established there should be no difficulty and very little expense in establishing second and subsequent rotation crops. Some species grow well in mixture with eucalypts and this may be one of the most useful features of *Callitris* in savanna afforestation. But the effect on the growth of the *Eucalyptus* is not yet known and needs to be determined by experiment.

In most savanna countries *Callitris* spp. are nearly all in the experimental stages and their place in afforestation has yet to be established. In Zambia, however, despite good survival and promising early growth of *C. huegelii* and *C. intratropica* on plateau sites (elevations of 1 100 to 1 400 metres, rainfalls of 600 to 1 200 millimetres and a five-month dry season), overall growth was very poor, and *Callitris* spp. are no longer adjudged promising. *C. calcarata* and *C. robusta* failed altogether. The following species have been tried under African savanna conditions.

Callitris calcarata A. Cunn. ex. Mirb. — Syn. *C. endlicheri* (Parl.) J. Garden (Black cypress pine)

Indigenous to Queensland, New South Wales and Victoria it covers a wide range of sites and climates. A straight tree producing good, termite-resistant poles and a fine timber.

In Rhodesia it is an important plantation species, popular for pole production and for filling gaps in eucalypt plantations. It is reported to do best in the midland plateau country with rainfalls of 500 to 1 000 millimetres a year on sand veldt and on deep soils derived from granite. It does not tolerate shallow or waterlogged soils. A representative stand at 15 years of age had a mean height of 11.6 metres and a mean diameter of 12 centimetres. While it is excellent for poles, a rather large percentage of twisted grain precludes sawing and results in splitting when turned for brushware. It seeds freely and regenerates naturally, particularly under eucalypts. Its ability to compete with the latter is considered a valuable asset.

Preliminary trials in Nigeria indicate that it is worth further testing in the northern Guinea and southern Guinea zones. Survival was good in all trials and two years after planting average heights were 1.2 to 1.5 metres with the tallest trees over 2.1 metres. Stems were very straight with strong leading shoots.

In other countries results have been variable. It failed in trials in Ghana and Zambia. In Malawi it was satisfactory and is recommended for more extensive planting for poles and timber. In Uganda it is "planted only in Ankole but considered suitable for Karamoja" (Streets, 1962). In South Africa results were poor in some climatic subdivisions, moderate in others. Good results were obtained only in a plantation at Entabeni on a deep loam at 1 400 metres' elevation with 1 900 millimetres of rain a year, i.e. in a moister climate than the semihumid tropical. There it reached a height of 23 metres in 34 years. The reasons for success or failure in the various countries are not recorded.

Callitris glauca R.Br. ex R.T. Baker & H.G. Smith — Syn. *C. huegelii* (Carr.) Franco (Murray river pine)

This species has often been confused with *C. robusta* (q.v.). It has a very wide distribution, occurring in areas in Australia down to about 360 millimetres of rainfall but with its best development in regions with 460 to 720 millimetres, where it attains heights of up to 30 metres. It should be possible to find provenances suitable for the dry tropical climatic type, but so far it has only been successful in the moister zones or at higher elevations, e.g. Rhodesia in the midland plateau country with a rainfall of 500 to 600 millimetres and an elevation of about 1 500 metres.

In Nigeria, early trials in the northern Guinea and southern Guinea zones were promising. Survival was satisfactory and, two years after planting, mean height was 2.1 metres with the tallest trees over 3 metres in the northern zone. In the rather moister southern zone heights were about 0.6 metres less. A trial in the Sudan zone was made on a poorly drained soil and few plants survived.

Like other *Callitris* species, it requires well-drained soils. The stem form was rather more variable than in other *Callitris* species tried, though it was generally good. Early height increment tended to be better.

Callitris intratropica Benth. & Hook. fil.

This species has been tried in Uganda, Zambia and northern Nigeria, with initially promising results. It is reported from Nigeria to have a rather bushier habit with a tendency to more frequent heavier branching than the other *Callitris* species tried. Early growth, up to five years, averaged about one metre per year in the north-

ern Guinea zone and slightly less in the southern Guinea zone. Otherwise its behaviour is similar to *C. glauca*.

Callitris robusta (A. Cunn. ex Endl.) F.M. Bailey — Syn. *C. preissii* Miquel

This species has been frequently confused with *C. glauca* and Pryor, 1969, suggests that most of the existing plantations named *C. robusta* are in fact *C. glauca*.

Apart from established plantations on the Jos Plateau in Nigeria, which at an age of 31 years have a mean height of 14.9 metres, it has not done as well as *C. glauca*. It failed in Zambia on sites where *C. glauca* and *C. intratropica* started satisfactorily and in South Africa it did not do well in comparison with other *Callitris* spp. In the northern Guinea and southern Guinea zones of Nigeria initial growth was, if anything, rather poorer than that of other species and no further trials are proposed.

Cassia siamea LAM.

Formerly this was one of the most widely planted and successful exotics. It was introduced into various countries in Africa mostly between 1910 and 1924. Extensive plantations were made in Ghana, Nigeria (western region), Zambia, Tanzania and Uganda (Streets, 1962). Raised mainly for fuel and poles, it has now been to a great extent displaced by *Eucalyptus* spp. which grow faster and give higher yields. It has one advantage over the eucalypts in being relatively resistant to termites. It requires well-drained soils relatively rich in nutrients and tolerates laterite provided the drainage is not impeded. In Sudan it is recommended for good, well-drained sands and silts along rivers and canals, and for irrigated plantations. It has a rather shallow root system and, though generally fairly drought resistant, it cannot stand competition for soil moisture. It is unsuitable for sites where *Imperata cylindrica* is present. On unsuitable soils, e.g. many sites in the Sudan zone of Nigeria, it often starts well with rapid early height growth, but checks after a few years and soon fails.

It is easy to raise either by direct sowing using about 3.4 kilogrammes of seed per hectare or by one-year stump plants or container plants. No seed pretreatment is necessary. Clean weeding is necessary in the plantations for the first one or two years. It coppices readily and fuel plantations are commonly worked on rotations of five to eight years or longer according to site conditions or whether poles are required in addition to fuel. The fuel is of excellent quality. The poles have a small heartwood and are not very durable. The leaves are sometimes used for fodder.

Cassia siamea is rarely used in plantations nowadays as, where it grows reliably and well, there are other species such as various eucalypts, *Gmelina arborea*, etc., which give higher yields of firewood and better poles.

Eucalyptus SPP.

Eucalyptus camaldulensis Dehn

Though mainly a species for the dry tropical climate, it has also been used in the semihumid tropical climate in trials in Zambia (northern plateau) and in the northern Guinea and southern Guinea zones of Nigeria. It shows a high rate of production and a wide tolerance of different soils. But, owing to the inferior stem form of most provenances hitherto grown in Africa and their poor ability to suppress grass, it compares badly with other species such as *E. cloeziana*, *E. propinqua* and *E. "grandis"* and, where these can be grown, they are to be preferred.

Eucalyptus citriodora Hook (Lemon-scented gum)

The attraction of this species is its fast growth, excellent bole form and good timber quality. It is a native of the central and northeastern coastal districts of Queensland, extending inland over 300 kilometres and occurring from sea level up to 600 metres. It grows in a subtropical to tropical climate with a summer rainfall. The minimum rainfall required is 600 millimetres in the cooler parts of its distribution, but for satisfactory growth over 900 millimetres is desirable. It tolerates rather drier conditions than *E. "grandis"* (q.v.) which is to be preferred in the moister parts of Climatic type 4 and in type 5 on account of its higher production. It is tolerant of a variety of soils.

In the northern and southern Guinea zones it has done well on deep well-drained sandy loams, typical height increment being 3 metres per year average over the first four years. It grows even faster in the derived savanna zone (Climatic type 5) though growth is variable. In

FIGURE 13. Nine-month-old plantation of *Eucalyptus citriodora* in central Sudan.
(*Courtesy* M. Reynders)

Sudan, it is recommended particularly for river silts with regular annual floods or irrigation. In Rhodesia it has grown satisfactorily in plantations in the higher rainfall areas on both dolerite and granitic soils. It is not very drought tolerant, though more so than *E. "grandis"* and can only survive slight frosts. Trials in Zambia have shown promising results on the northern, central and southern plateaux at elevations of 1 100 to 1 400 metres with average early height growth of 3 metres or more. It does not, however, attain the growth rates of *E. "grandis"* on the same sites. On the Kalahari sands it was cut back by frosts. In trials in Congo under a mean annual rainfall of 1 200 to 1 300 millimetres it was unthrifty on the sandy soils of Pointe-Noire but succeeded on the clays and sandy clays of Loudima where it reached a mean height of 13 metres and a mean diameter of 11 to 13 centimetres in four years. The mean annual increment over this period down to 6.5 centimetres' diameter was 12 cubic metres per hectare.

Silviculturally, *E. citriodora* used to have the reputation of being difficult to establish, and undoubtedly it does not transplant readily either in the nursery or in the field as a naked rooted transplant, nor does it succeed as a stump. Failures were attributed to the fatal effect of cutting or breaking the tap root. With modern polythene pot techniques, however, there seems to be little difficulty in obtaining high survival and good early growth. The tree seeds plentifully every year. The seed is large for a eucalypt (150 to 220 seeds per gramme). Two or three seeds are sown per pot. Germination is generally high — over 75 percent — and seedlings should be reduced to one per pot at an early stage. They take about two months to reach a height of 15 centimetres but thereafter growth is very rapid and ten to eleven weeks are usually sufficient to produce plants 30 to 45 centimetres high. Under favourable conditions direct sowing is successful, three to five seeds being sown per spot at 2.4 × 2.4 metres' spacing.

Good ground preparation is essential and since the species is very susceptible to termite damage, the usual precautions of mixing insecticide into the potting mixture and into the soil of the planting pit are necessary. Clean weeding in the early years is important. The species is relatively free from diseases and pests.

It is fairly fast growing, 2.5 to 3 metres a year when young and 30 metres' height is attained in less than 15 years on good sites. There are indications that growth can be improved by the use of nitrogenous fertilizers on some sites. On others, some die-back has been experienced, but this can usually be cured by applications of borate fertilizer. The crown of the tree is high and light and the shade cast is insufficient to suppress grass.

The tree has a straight, clean bole even when grown at wide spacings. The timber is hard, strong, tough and heavy (1 030 kilogrammes per cubic metre or 64 lbs per cubic foot). It is durable and is easy to work. It is a first-class saw timber and is used for heavy and general construction. It also turns well and makes good tool handles. Citronella oil is sometimes distilled from the lemon-scented leaves.

Height increment is nearly as good as that of *E. "grandis"* but diameter increment is considerably slower. The wood of *E. "grandis"* is also useful for timber and has the advantage of being some 20 to 30 percent lighter. Where conditions are suitable for good growth of *E. "grandis"* it is to be preferred to *E. citriodora* though there may be a place for the latter where conditions are too dry for the best growth of *E. "grandis."*

Eucalyptus citriodora × *E. torelliana* (hybrid)

This hybrid, which appeared spontaneously in plantations from local seed on the Jos Plateau of Nigeria, grows much faster than either parent. It has a denser crown and much faster diameter increment, though less good form and more taper than *E. citriodora*. It is considered sufficiently

interesting to justify further growth trials and research into its improvement by controlled pollination between selected parent trees.

Eucalyptus cloeziana F. v. Muell.

This species comes from the coastal and interior parts of Queensland where it has a discontinuous distribution. It occurs in areas with a summer rainfall varying from 760 to 1 650 millimetres and attains its best growth on the moist valley slopes in the higher rainfall areas. In South Africa it has become an important plantation species in the moister summer-rainfall regions. It has been introduced into various other African countries including Kenya, Malawi, Uganda, Zambia and Nigeria. Its attractions are its fast growth, long clean stem of good form and its dense crown. The timber is hard and heavy and has limited uses for general construction but is excellent for railway sleepers, mine timbers and poles, particularly telegraph and transmission poles.

In Zambia, on the northern and southern plateau sites early top-height increments varied from 2.9 to 4.0 metres per year and diameter increments from 2.5 to 3.8 centimetres a year. In Nigeria the best growth was in the derived savanna zone (Climatic type 5) where a mean annual height increment of 1.8 metres was achieved over the first five years, at which age the tallest trees were 12.2 to 15.2 metres high and 12 to 15 centimetres in diameter.

In the southern Guinea zone in Nigeria early height increment in the first two years was 2.1 to 2.4 metres per year, while in the northern Guinea zone top height trees at 4½ years were 14.6 metres tall with a diameter of 16.8 centimetres. The latter plot had been mechanically weeded.

Seed fertility is variable and the germination capacity sometimes low. Sowing rates in Nigeria vary from 1 to 2 grammes per 100 pots. Early growth is slow and four months are needed to produce plants 38 centimetres high. It is reported to be rather susceptible to damping off in the nursery.

This species is said to be somewhat difficult to establish in plantation. Survival rates have been low on some sites necessitating beating up in the second year. The stem form in plantations is excellent and the compact crowns cast sufficient shade to suppress grass at an early stage. It appears to be more tolerant of low boron availability than many other *Eucalyptus* species. If any die-back appears, application of commercial borate fertilizer should not exceed 30 grammes per tree. As it has a discontinuous distribution in its country of origin, provenance trials may be desirable to find out the best provenances for any particular site.

This species is strongly recommended for the moister parts of the semihumid tropical climate (e.g. the southern Guinea and possibly the northern Guinea zones of Nigeria and the northern plateau sites of Zambia), on deep well-drained soils. It is unlikely to grow well in drier areas such as in the Sudan zone of Nigeria, except on very limited sites of exceptional moisture and nutrient availability.

Eucalyptus " grandis "

(Under this heading are included: *Eucalyptus grandis* Hill ex Maiden, *Eucalyptus saligna* Sm. and hybrids that have been planted so extensively under the names *E. " saligna "* or *E. " grandis."*)

There has been much confusion over the identification of the species included in the *E. " grandis "* complex. Most of the stands grown in South Africa, from which seed has in the past been sent to a number of other countries in Africa, and which were previously described as *E. " saligna,"* are now considered to be of mixed origin, but considerably closer to true *E. grandis* than to true *E. saligna*, but every stage of hybridization occurs from pure *E. grandis* to pure *E. saligna*. In the present text the name *E. " grandis "* is used to denote the common form grown from African seed. In some cases, additional species have been involved in hybridization. For example, plantations designated *E. " saligna "* in Nigeria are considered by Pryor, 1970b, to have originated from interbreeding between a species of the Transversae (probably *E. grandis*) and one of the Exsertae (probably *E. camaldulensis*).

Both *E. saligna* and *E. grandis* come from eastern Australia. Their ranges overlap in New South Wales and southern Queensland but *E. grandis* extends further north in Queensland than *E. saligna*. Where they grow together there is every possibility of seed of the two species being mixed and of natural hybrids occurring. They are both very large trees and come from areas with a rainfall of 900 to 1 270 millimetres, fairly

well distributed throughout the year, but with a marked summer maximum, especially toward the north of their range.

The timber of *E. saligna* is reported to be hard, tough, strong and moderately durable, rather coarse-textured, moderately light, easy to work and finish. That of *E. grandis* is lighter, softer and more fissile than that of most eucalypts, with moderate strength and durability, prone to warping and other defects especially when sawn from young or fast grown trees (Streets, 1962). The timber quality of fast grown hybrids would seem to need examination. Both species and the hybrid make good poles but need preservative treatment for telegraph and transmission poles.

Only small areas of authentic *E. saligna* and *E. grandis* of Australian origin have been planted in savanna conditions. In trials in Zambia it was found that *E. saligna* was more drought sensitive than either *E. grandis* or *E. "grandis"* from Africa.

As regards sites, much of the most successful planting of *E. "grandis"* in Kenya and Malawi has been done at high altitudes outside the savanna region, and in other countries in conditions of rainfall and moisture corresponding to moist high forest types. Phenomenal rates of production have been achieved under such favourable conditions. In Rhodesia, mean annual increments of 61 to 66 cubic metres per hectare have been recorded on the best soils in high rainfall areas (Barrett and Mullin, 1968). This is, however, exceptional. The tree requires good deep permeable soils and cannot stand poor drainage or waterlogging. At the same time it cannot tolerate drought. A rainfall of 900 millimetres and upward, with a not too severe dry season, is suitable. In Zambia, where it is the major plantation species, it grows excellently on the northern plateau at elevations of 1 220 metres and a rainfall of about 1 200 millimetres, where it achieves a mean annual top-height increment of 5.1 metres and a mean annual diameter increment of 4.2 centimetres in two to four years. For the Zambian plantations as a whole, which are all at elevations over 920 metres and rainfall of 750 millimetres or over, average height growth is about 30 metres in eight years.

E. "grandis" was tried in Congo under a rainfall of 1 200 to 1 300 millimetres, but with a four-month dry season. Though it started well, after the first three years its condition deteriorated and this was attributed to shortage of water (Groulez, 1967c).

In northern Nigeria the putative hybrid between *E. grandis* and *E. camaldulensis* termed *E. "saligna"* (see p. 60) is one of the most promising eucalypts in the semihumid and humid tropical climates. Potential rates of production are greater than those of any other species so far tested in the northern Guinea, southern Guinea and derived savanna zones, with the exception of *E. camaldulensis*, but its ability to maintain high rates of growth under the more severe conditions of parts of the northern Guinea zone has yet to be proved.

E. "grandis" in its various forms sets seed at an early age. It is relatively easy to handle in the nursery. Seed is sown direct into pots at the rate of 1 gramme per 100 pots. Height growth is rapid and most seedlings reach a height of 30 centimetres in ten weeks. In Zambia smaller plants not more than 23 centimetres high are preferred. As for all *Eucalyptus* planting clean site preparation is desirable, and indeed essential where moisture is likely to be short at any time of the year. Clean weeding is necessary until the canopy has closed enough to suppress grass and invading weeds. The species is susceptible to termite attack and the usual precautions of applying insecticides at the time of planting have to be taken, especially on the drier sites where termite damage is always more severe. It also suffers from die-back on boron-deficient soils and, in such cases, application of borate fertilizer may be necessary.

Eucalyptus pilularis Sm. (Blackbutt)

One of the most important hardwoods of Australia, this species comes from New South Wales and the southern part of Queensland. This is a large tree of excellent form with a deep narrow crown which casts sufficient shade to suppress grass growth in plantations. It usually needs over 1 000 millimetres of rain a year under savanna conditions, doing better where the rainfall is higher. This species is very susceptible to termite attack and application of insecticide after planting is recommended. It does not seem to suffer from boron deficiency.

Trials in different parts of Africa (Kenya, Malawi, Zambia as well as in South Africa) have shown promise, though it has nowhere been planted yet on a large scale. Its early growth is rapid. In Nigeria after a promising start in

the northern Guinea zone, it began to suffer numerous deaths and must now be considered a failure. This applied to all fifteen provenances tested at Afaka.

Eucalyptus propinqua Deane & Maiden

This species, which is one of the prime structural timbers of Australia and is in the highest class for both strength and durability, comes from New South Wales and south Queensland, from regions with a rainfall of 900 to 1 400 millimetres per year. It has excellent stem form and the foliage casts a sufficiently dense shade to suppress grass growth in plantations.

Though apparently not widely tested in Africa, trials in northern Nigeria have given such good early results that it is regarded as one of the most promising species so far tried in the northern Guinea and southern Guinea zones. It may also have a place in the Sudan zone on deep well-drained soils with a dry-season water table at not more than about 6 metres. It did not grow well in the wetter derived savanna zone. On some sites it suffered severe termite attack, against which the usual precautions should be taken. It appears to be slightly susceptible to boron deficiency, and application of commercial borate fertilizer at up to 50 grammes per tree is recommended.

Eucalyptus saligna Sm.

As there has been considerable confusion between *E. grandis* and *E. saligna,* and as they hybridize, and have similar silvicultural requirements, this species is discussed under *E. "grandis."*

Eucalyptus tereticornis Sm.

This species has already been mentioned under the dry tropical climatic type. In the moister conditions of the semihumid tropical climate, it is usually inferior to other species such as the *E. "grandis"* complex. In general, although the stem form may be better, the survival and height growth of most *E. tereticornis* provenances are poorer than that of *E. camaldulensis*, particularly on the poorer sites. An exception is experienced in Zambia, where *E. tereticornis* is usually more drought and frost resistant than *E. camaldulensis*. A hybrid between *E. tereticornis* and *E. "grandis"* is already proving successful in several areas in combining the form and growth rate of *E. "grandis"* with the drought and frost resistance of *E. tereticornis* (Greenwood, 1973).

In Congo, which has a typical semihumid tropical climate, with a mean annual rainfall of 1 200 to 1 300 millimetres and a four-month dry season, a variety known as "*Eucalyptus* sp. 12 ABL" after its place of origin, Ambila-Lemaitso in Madagascar, was introduced in 1956. It was first thought to be a hybrid of *E. camaldulensis* (Groulez, 1967c) but later investigation has established that it is a provenance of *E. tereticornis* from northern Queensland (Martin, 1971). This variety has done exceptionally well. It has a high percentage of straight, cylindrical stems and natural pruning is good. At the age of four years, planted at an espacement of 3.25 × 3.25 metres, on deep sands at Loandjili near Pointe-Noire, the mean diameter and height were 11 centimetres and 12 metres respectively, and at Loudima on clay or sandy clay, 13 centimetres and 15 metres respectively. The mean annual increment of wood down to 6.5 centimetres in diameter was 12 to 14 cubic metres/hectare/year at Loandjili and up to 20-22 cubic metres/hectare/year at Loudima. This variety has become the principal one used in extensive plantations for firewood (Groulez, 1967b). It is markedly superior to any provenance of *E. camaldulensis* tried, but recent introductions of *E. tereticornis* provenances from the Herberton and Mt. Garnet areas of northern Queensland have shown these to be almost identical in appearance with *E.* sp. 12 ABL and at least as fast-growing (Martin, 1971).

The provenance from Mysore, India (see also p. 47), has been tried in various places and the indications are that it may prove superior in growth rate and in average form to the other provenances of *E. tereticornis* and to *E. camaldulensis.* In the semihumid tropical zone of Nigeria, this and a provenance from north Queensland have given best results. Owing to the great variability of the Mysore provenance, the possibilities of further hybridization between it and *E. "grandis"* are worth exploring.

Like *E. camaldulensis, E. tereticornis* is primarily a species for fuel and small pole production. Its form is too poor for timber or for the larger poles for transmission or telegraph lines where the specifications regarding straightness are generally very strict.

FIGURE 14. Four-year-old plantation of the "Mysore hybrid" of *Eucalyptus tereticornis* near Korhogo, Ivory Coast.

(*Courtesy* P.J. Wood)

Pinus SPP.

Of all the species of pines that will grow in tropical latitudes, only very few are suitable for planting in savanna conditions. The species that are extensively cultivated at higher elevations, *P. radiata, P. patula,* etc., are quite unsuitable and even *P. elliottii* (formerly considered to be a northerly provenance of *P. caribaea*) is rarely successful under about 1 200 metres.

From the climatic angle, none of the pines will grow satisfactorily in the dry tropical climatic zone. A few species will grow well in the moister parts of the northern Guinea zone and in the southern Guinea zone of Nigeria as well as on the plateau sites of Zambia at elevations of 1 050 to 2 350 metres. They will also grow well in parts of the derived savanna zone but here they are in competition with other high-value fast growing plantation species and are unlikely to be planted unless there is a special demand for coniferous timber (e.g. for long fibre pulp). At lower elevations and in the hotter climates *P. caribaea* var. *hondurensis* has so far given the best results, while in Zambia in the somewhat less rigorous climate at the higher elevations *P. kesiya,* both Vietnamese and Philippine strains (the latter formerly known as *P. insularis*), has proven the most suitable, while plots of one provenance each of *P. oocarpa* var. *oocarpa* and *P. oocarpa* var. *ochoterenai* are very promising up to ages of 11 and 8½ years respectively. In all cases it is crucial that the right provenance should be used.

In Congo, extensive trials of coniferous species have been carried out over the last seven years and, out of about 74 species tested, the most satisfactory were *Pinus caribaea* var. *hondurensis* and *P. oocarpa* var. *ochoterenai.* The best growth was at Brazzaville at 600 to 700 metres elevation on sandy steppe soils, but growth was also satisfactory at Loudima at 150 to 200 metres on a clayey peneplain soil and at Pointe-Noire at 50 to 70 metres; performance improved with increasing altitude. The rainfall was in all cases 900 to 1 600 millimetres with a marked ecologically dry season of four months (Groulez, 1967d; Martin, 1971).

In general, pines do not require a high level of soil fertility, but in Nigeria, on most sites, healthy growth can only be obtained if phosphate is added. The general practice there is to apply 100 grammes of superphosphate per tree soon after planting.

In many trials variable results have been obtained and species have been rejected on account of poor survival and growth which in later trials have proved successful. This is frequently connected with the presence of a suitable mycorrhizal fungus in the soil, without which pines often fail to grow. This appears to be more important where the soils have a high pH than on acid soils. The ease of mycorrhizal establishment is also connected with the nutritional status of the soil. Where the soils are exceedingly poor in nutrients, especially phosphorus, mycorrhizae do not readily form, nor will the pines grow. In very rich soils, with more than adequate P and N, mycorrhizae are usually weakly developed and, indeed, are not then so necessary for the health of the pines. It is in the intermediate conditions that mycorrhizae are most essential. Acid sandy soils with an adequate P content (over about 100 ppm) are most favourable to mycorrhizal

development and it is in such conditions that pines must have mycorrhizae for healthy growth. If the soil is not already infected it is essential that suitable fungi be introduced, either by importation of soil which is heavily inoculated with mycorrhizae from successful plantations or by ensuring that the nursery stock used has formed a mycorrhizal association. It is impossible to judge the growth potential of different species and provenances of pines unless and until it is certain that the site has become fully infected with suitable fungi and that the pine roots are freely forming mycorrhizal associations.

FIGURE 15. Distorted needles of two-year-old *Pinus oocarpa* in Nigeria, believed caused by low air humidity during the dry season.

(*Courtesy* P.J. Wood)

One abnormality which is common in pines, particularly *P. caribaea* and *P. oocarpa*, in the Nigerian savanna is the tendency to produce crumpled needles during dry-season growth. It is believed that the needle sheath becomes desiccated and hard, so that the needles start to expand within the sheath before they can rupture it. The recurrence of this abnormality over several years produces a regular alternation of normal needles formed during the wet season and crumpled needles formed during the dry season. A small trial carried out indicated that this was the result of air moisture rather than soil moisture relations; dry-season watering did not prevent the formation of crumpled needles, while enclosing individual shoots in a moist atmosphere within a polythene bag produced normal needles. The phenomenon continues to some age and was noted in a nine-year-old plot of *P. caribaea* at Miango on the Jos Plateau. It was more marked in the upper and outer shoots, which are most exposed to accelerated transpiration, and less marked or absent in the shaded lower and inner shoots. There is as yet no evidence that this abnormality affects the growth of the trees, but the comparison of photosynthetic capacity of normal and crumpled needles would be a worthwhile physiological study (Jackson, 1970).

Though some pines have been introduced many years ago under tropical conditions in Africa, it is only recently that the systematic testing of provenances and varieties suitable for low levels in the tropics has begun. The work is still in its early stages and much more research is needed before the best provenances and varieties for particular conditions are reliably known and their productive potential determined. The following provisional information on species and provenances is based on the indications of research and experience gained so far.

Pinus caribaea Morelet

This species has a very wide natural distribution, and the provenance that has so far shown the most promise is of the variety *hondurensis* from the Mountain Pine Ridge of British Honduras. The climate there closely matches that of the southern Guinea zone of Nigeria, and this provenance grows well in both that zone and the somewhat drier northern Guinea zone. The species prefers deep well-drained sandy soils including sandy loams and sandy clays. They must be unimpeded so that the roots can reach the water table which may be as low as 3 metres or more below the surface. Growth is adversely affected by a high or fluctuating water table and is better where seasonal variation is limited, even though the average depth of the water table is greater. It grows well on the Jos

FIGURE 16. Three-year-old experimental plot of *Pinus caribaea* at Afaka, Nigeria.
(*Courtesy* J.K. Jackson)

Plateau of Nigeria at 1 200 metres' altitude, where it shows greater vigour than *P. kesiya.* In Zambia it shows promise on deep sandy soils and clayey sands in areas with over 800 millimetres of rainfall at elevations of 900 to 1 500 metres, but so far has not done so well as the well-tried and now extensively planted *P. kesiya* from the Philippines or Viet-Nam. In the derived savanna zone of Nigeria, with its higher rainfall and generally moister conditions, it has shown promise, also in Congo (Groulez, 1967d; Martin, 1971).

In the nursery, seed which has been pregerminated in moist sterilized sand/vermiculite is sown directly into polythene pots. The soil mixture should contain a small proportion of soil from a successful pine plantation in order to infect it with the necessary mycorrhizal fungus. The total time in the nursery from the start of pregermination is about six months.

In plantations, complete clearing of the site including stump removal is desirable, and clean weeding is desirable in the early years except where abundant soil moisture is available all the year round. (e.g. it can be seen growing vigorously in dense *Imperata cylindrica* grass in Malaysia). In Nigeria, delay in cultivation resulting in thick grass growth caused yellowing of the needles. After cultivation their previous healthy green colour was restored.

The tree has, in general, good stem form. Growth continues throughout the year on many sites, though on others, if subsoil water is short at any season, there may be a check in growth. Some "foxtailing" (absence of lateral branches for several consecutive years) occurs on individual trees and sometimes fused or constricted folded needles are developed in the dry season without, however, any evident effect on tree growth. Wood properties show great variation both between sites and between trees. In general, fast-grown plantation crops have wood which is very different from that of slow-grown trees from natural forests. Since the great majority of plantations are very young still, it is impossible to draw general conclusions about wood properties and uses, but some intensive investigations have been, or are being, carried out (Hughes, 1970, 1971).

From the evidence of current trials and the known performance in other countries, this species appears to have great promise for planting in the moister savanna areas under tropical conditions. The provenance from the Mountain Pine Ridge in British Honduras is the fastest growing and most vigorous so far tested, but further provenance trials are desirable, particularly of the most southerly, tropical provenances of var. *hondurensis* near the equator and of var. *caribaea* and var. *bahamensis* in higher latitudes.

Pinus kesiya Royle ex Gordon — Syn. *P. khasya* Royle and, in part, *P. insularis* Endl.

This pine has a wide range of distribution from the Khasi hills in Assam through Burma, Thailand, Laos, Cambodia, and Viet-Nam to the Philippines. The Philippine strain, known as "Benguet pine," was formerly regarded as a separate species, *P. insularis* Endl.

In Zambia it is the most widely planted of the pines. It is found to be fast growing and relatively adaptable to differing site conditions. The main successful plantations are at elevations of 1 050 to 1 350 metres with rainfall ranging from 900 to 1 800 millimetres. Under these conditions it has shown more consistently high rates of survival and better growth than the tropical low altitude pines such as *P. caribaea*. The only other species showing comparable results is *P. oocarpa* (up to age 12). Trials of *P. kesiya* from mainland origins (Burma, Thailand, etc.) have in most cases proved inferior, both in rate of growth and in form, though seed from Dalat

FIGURE 17. A good specimen of *Pinus kesiya*, two years old, at Ndola, Zambia.

(*Courtesy* Forest Department, Zambia)

district in South Viet-Nam has given results comparable with the Benguet (Philippine) provenances.

In trials in Nigeria *P. kesiya* has been found to be more difficult to establish and to grow more irregularly than *P. caribaea* in the northern and southern Guinea zones, but this may have been due to a delay in development of satisfactory mycorrhizal conditions. There are indications that seed from Zambian plantations may produce better growth than seed imported direct from the Philippines owing, presumably, to selection for vigour and superior stem form in the process of normal silvicultural thinnings. More trials of this species are desirable, particularly in respect of selection of seed trees. At present, however, both *P. caribaea* and *P. oocarpa* appear to warrant prior consideration over *P. kesiya* in Nigeria, especially at elevations below 600 metres.

In other parts of Africa, encouraging results with *P. kesiya* are reported (Streets, 1962) from Kenya, Rhodesia and Malawi, but in none of these countries is it used extensively in plantations. It has also given promising results in several parts of South Africa, but does not grow as well as *P. merkusii* at low elevations.

Pinus merkusii Jungh & de Vriese (including *P. merkusiana* Cooling & Gaussen)

This species has an even wider natural range of distribution than *P. kesiya,* and occurs from northeastern India through the mainland of Southeast Asia to Sumatra and the Philippines. Where it overlaps *P. kesiya* it is normally found at lower elevations in more tropical conditions. It grows in conditions varying from a savanna-like type of climate in central Thailand to continually humid, high rainfall climates in Indonesia (Cooling, 1968a).

The variation in the species from different parts of its range is considerable, and the difrences between the characteristics of the Indonesian and continental provenances are so great that they have recently been split into two species — *Pinus merkusii* Jungh & de Vriese in Sumatra and *P. merkusiana* Cooling & Gaussen (1970) for the continental forms.

The Indonesian strains are faster growing than the continental, have no "grass stage" when young, are less drought tolerant and have poorer form. The continental strains have excellent bole form and, coming mostly from less humid regions, are more tolerant of dry spells, but can be expected to be slower growing. They are adapted to withstand fire when young and have a definite "grass stage" (like *P. palustris* in the southern United States), which may last for several years.

Although *P. merkusii* has considerable potential for plantations under the less extreme savanna conditions, very little research has so far been done. This is probably due to difficulty in getting seed and in transporting it as it appears to lose its viability quickly. Seed crops, especially in Sumatra, are often very light, and seed ripening may occur throughout the year, thus increasing the difficulty and cost of seed collection. Indonesian and Vietnamese strains have been tried in Zambia with promising initial results. Although they have shown great adaptability to different silvicultural types and to a variety of soils within these types, height growth fell off badly after 21 years when compared to *P. kesiya.* Diameter growth was still comparable, but form is generally poor and the grass stage of the continental *P. merkusiana* is eco-

nomically unacceptable. As reliable alternatives to *P. kesiya* in Zambia, *P. merkusii* and *P. merkusiana* are now considered less promising than the various strains of *P. oocarpa* and *P. caribaea*. Elsewhere in Africa there is very little information from trials, with the exception of South Africa where Streets, 1962, reports variable rates of growth and bole form. The fastest growth was in a plantation under a 1 470-millimetre rainfall and an annual mean temperature range of about 19 to 32°C, where a mean height of 25 metres and a diameter of 33 centimetres were reached at an age of 19 years. Other plantations showed better form and health, though not such fast growth. Unfortunately no mention is made of the provenances used. In Malawi it is reported that this species is under trial at 600 to 1 800 metres with a minimum annual rainfall of 1 000 millimetres and a mean annual temperature of 16 to 19°C, but no results are given nor are the provenances mentioned.

Generally, *P. merkusii* may be expected to be more suitable than *P. kesiya* for hotter and more tropical sites and the systematic testing of a wide range of provenances should have high priority in any country interested in tropical pines. Research is also needed into methods of maintaining the viability of the seed.

Pinus oocarpa Schiede

Less is known about this Central American pine than about *P. caribaea*, though certain provenances have shown it to have equal promise for planting in really tropical conditions. Its natural distribution ranges from northern Mexico throughout Central America to Nicaragua and it occurs on the mountains of both the Pacific and Caribbean coasts. It varies from a small tree with a rather crooked bole in the north of Mexico to a large tree over 30 metres high in the south with a very fine straight bole. A variety, *P. oocarpa* var. *ochoterenai*, occurs in British Honduras, Guatemala, Honduras and southeast Mexico (Chiapas) and has given especially good results in trials in Africa, notably in Congo (Martin, 1971).

In Nigeria, provenances from British Honduras (presumably var. *ochoterenai*) have equalled *P. caribaea* in performance in early years, both on the Jos Plateau and at Afaka in the northern Guinea zone. The trees had thin horizontal branches in regular whorls and contrasted with south Mexican provenances which had heavier

FIGURE 18. Recently pruned plantation of *Pinus oocarpa*, twelve years old, at Ndola, Zambia.
(*Courtesy* Forest Department, Zambia)

irregular branching and denser tufts of needles.

In Zambia, the variety *ochoterenai*, where identified, did better than most provenances of var. *oocarpa*, and equalled *P. caribaea* in performance, but, like the latter, it showed itself less well adapted to the higher altitudes and less severe tropical conditions of Zambia than *P. kesiya* from the Philippines. One provenance of *P. oocarpa* var. *oocarpa* (Honduras, Valle de Angeles, District Francisco Morazan) has, however, shown good form and excellent growth (mean height 17.44 metres and mean diameter breast height 21.3 centimetres at just under 10 years, as compared to 17.39 metres and 21.7 centimetres for Philippine *P. kesiya*) and is a strong contender as an alternative to *P. kesiya*.

An examination of the needles of *P. oocarpa* suggests that it is likely to be better adapted than *P. caribaea* to growth in a dry atmosphere as it has a nonabsorbent, waxy leaf surface. It seems likely that it will, on that account, be

better suited to withstand the dry harmattan wind of northern Nigeria than any of the other low-level tropical pines so far examined.

In general, this species merits more intensive investigation as a tropical plantation pine likely to be suitable for low- and medium-level savanna areas in the semihumid and humid tropical climates on well-drained soils. High priority should be given to provenance trials with seed from the southern part of its range (British Honduras, Guatemala, Honduras and Nicaragua). Good varieties should be selected (e.g. the variety *ochoterenai* already mentioned) and seed orchards established. Where adequate seed of good varieties is available, plantation trials comparing it with *P. caribaea* should be laid down on suitable sites.

Climatic type 5. Humid tropical and equatorial

This is the wettest of the savanna climatic types. It usually has two rainfall peaks during the year and 0 to 3 dry months; humidity is generally high. Rainfall is usually over 1 500 millimetres. It normally supports a moist to wet high-forest type of vegetation, and would not come within the scope of this publication were it not for the existence of large areas of " derived savanna " caused by clearing and burning and maintained in a savanna condition by uncontrolled annual fires. There is a wide belt of derived savanna across much of west Africa north of the high forest and it is found elsewhere in Africa, e.g. in Uganda and in eastern Madagascar. In spite of the humid climate, the general appearance of the vegetation is that of savanna, and such areas present the most favourable opportunities for economic afforestation. On the Vegetation map (see maps, centre inset), the forest-savanna mosaic consists of a mixture of derived savanna and high forest relicts.

The species that can be used are mostly the same as would be used in the conversion of mixed high forest to plantations. The choice is wide and is determined largely by the soil conditions, as the supply of moisture is rarely, if ever, limiting. Where social conditions permit, taungya is usually feasible.

The following species are selected as being the most likely to give the best economic results, but there are many other useful species that may merit consideration for particular purposes.

Acrocarpus fraxinifolius Wight

This species is a native of the wet mixed evergreen forests of India where it is found as scattered individuals in the forests of the western Ghats, Assam, Chittagong and Burma. It is a tree of the high rainfall localities where it attains a considerable size, up to 60 metres in height and 240 centimetres in diameter above buttresses (Troup, 1921). It is grown as a shade tree in coffee plantations in India in areas of 1 800 millimetres of rainfall and over. It is very fast growing in youth and has a good stem form. The bark is thin and is reported to be sensitive to sun scorch. The timber is of good quality, fairly hard and works easily.

It has been introduced into many parts of Africa, mainly as an ornamental tree at higher elevations, outside the savanna. In Kenya it was introduced as long ago as 1913. It has been grown experimentally in plantations and is said to be well adapted to the lower altitudes of the highlands with rainfalls of 750 millimetres or more. In Malawi it is under trial for timber production at elevations from 600-1 800 metres with a minimum rainfall of 750 millimetres and a mean annual temperature of 16-24°C.

At Nimbia, Nigeria, in a rainfall of 1 500 to 1 800 millimetres at an elevation of 600 metres on a well-drained clay loam, it grew rapidly for the first four years. Mean height was then 10.7 metres and mean diameter 9.5 centimetres, while corresponding measurements for the dominants were 15.2 metres and 14 centimetres. Thereafter the trees stagnated. It is clear that at low elevations, even in the relatively moist conditions of the derived savanna, disappointing results may follow a very promising start.

The seed varies in weight from about 13 to 32 seeds per gramme. The seed is pregerminated in moist sterilized sand after treatment to stimulate germination (immersion in boiling water for a few seconds, followed by soaking in the same water while cooling for about 12 hours or, alternatively, immersion in sulphuric acid of specific gravity about 1.7 for 20 minutes). Germinated seed is pricked out into pots in full sunlight. Seedlings are ready for planting three months after germination, when they are 30 to 46 centimetres high. Experiments at Nimbia, Nigeria, showed that large plants of *Acrocarpus fraxinifolius* made strikingly better growth after planting out than small ones.

Plantations need to be kept free of grass and weeds until the canopy has closed sufficiently to suppress them. (In Nigerian trials this was at the end of the second season after planting at 1.8 metres' espacement.) Thinning of the best plots is probably necessary in the third or fourth year. In old plantations the crown spread is very considerable and it is necessary to thin to a wide final spacing.

Within the savanna, it appears likely that suitable sites for this species will be restricted to the cooler conditions near the upper limits of elevation. Even here, its status can only be ascertained after plantation scale trials have been made and measured throughout the best part of a rotation.

So far, this species has been remarkably free from pests and diseases, though occasionally it has suffered from termite attack when young.

Araucaria cunninghamii Sweet (Hoop pine)

Though mainly a tree for Climatic type 4, it may well grow even better in the humid tropical climate, and tests should certainly be extended to sites in the derived savanna where the soils are too good for pines. Being an excellent, long-fibred pulpwood, there may be a demand for it for mixing with hardwood pulps such as *Gmelina* in order to give extra strength to the paper. For further information about this species see under Climatic type 4 (p. 55).

Chlorophora excelsa (Welw.) Benth. & Hook. (Iroko, Mvule) and *Chlorophora regia* A. Chev. (Iroko)

These two closely related species are indigenous to the moister forests of the derived savanna and mixed semideciduous forests. *C. regia* is found from Sierra Leone to Ghana, while *C. excelsa* occurs from Ghana eastward through Nigeria and across the African continent to the east coast.

They produce excellent and indistinguishable timbers of commerce known as Iroko in the west and Mvule in the east. Many attempts have been made to grow them in plantations but these have nearly always failed owing to attacks by gall-forming insects of the genus *Phytolyma*. Formerly it was believed that the species *P. lata* attacked both of the *Chlorophora* species alike, but recently it has been established that *P. lata* can only breed on *C. regia* and that *C. excelsa* is attacked by another species, or possibly a complex of species, which do not affect *C. regia* (Browne, 1968; White and Eastop, 1965).

When *C. regia* is planted in Nigeria it is not attacked and this gives rise to the hope that it may be possible to raise plantations of it in the derived savanna zone and in other countries where the true *P. lata* is absent. Conversely it may be worth while carrying out plantation trials of *C. excelsa* in Sierra Leone where the particular species of *Phytolyma* that attack it are absent, as it is known that the true *P. lata* does not breed successfully on *C. excelsa*.

Trials of *Chlorophora regia* at Nimbia in the derived savanna zone and at Mokwa in the southern Guinea zone of Nigeria have shown good early growth on deep, well-drained loams or clay loams. Planted at 1.8 × 1.8 metres it is expected to close canopy in about three years. Further growth plots and plantation trials have been recommended for the southern Guinea and derived savanna zones, especially on some deep, poorly drained soils unsuitable for teak (Kemp, 1969, 1970).

Both *Chlorophora* species occur most commonly in secondary lowland high forest, following cultivation, or as isolated relicts in agricultural land. They often produce both root suckers and coppice shoots after felling and these are probably an effective means of regeneration under conditions of natural regeneration (Farrer, 1960; Jones, 1957).

Eucalyptus spp.

The following species, already mentioned in more detail under Climatic type 4, deserve further trials in the humid tropical climate of type 5, where they have already shown promise in small plots: *E. citriodora*, *E. cloeziana*, *E. "grandis"* and *E. propinqua*.

Another, more tropical species that may be worth considering is *E. deglupta* Blume (Syn. *E. naudiniana* F. v. M.) which occurs from New Guinea to the southern Philippines. A tree of high rainfall areas, it is probably best suited to high-forest sites and climate. It might, however, have a place in derived savanna on seasonally waterlogged sites that are unsuitable for teak.

Whether it will be economic to grow any of the above species in derived savanna will depend on their ability to grow on soils unsuitable for the good growth of teak and *Gmelina*. Both

these species require rather special soil conditions for high production and their growth falls off rapidly as conditions become less ideal for them. There may well be many sites submarginal for their satisfactory growth where some of the eucalypts may be more economic.

Gmelina arborea L. (YEMANE, GMELINA)

A comprehensive account of this species has been given by Lamb, 1968. The following notes have been taken largely from that publication, which should be referred to for further detail.

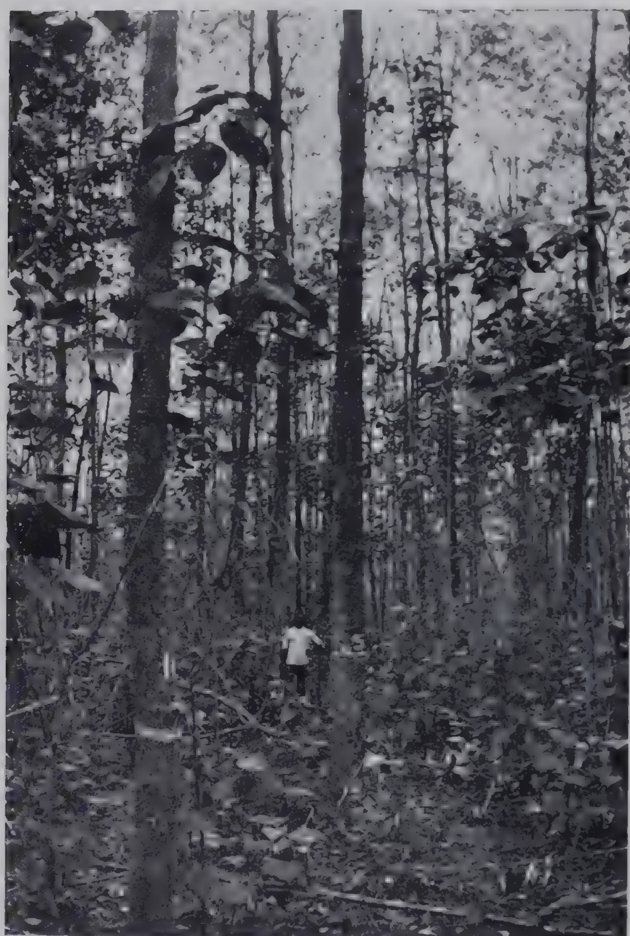


FIGURE 19. Twelve-year-old stand of *Gmelina arborea* at Nimbia, Nigeria.

(*Courtesy* P.J. Wood)

This tree has now an established place in the plantation programmes of many countries in Africa, and particularly in Sierra Leone, Nigeria and Malawi. Its attractions are that it is very fast growing in youth, is an excellent multipurpose timber, a good plywood that peels without the necessity of boiling the logs, and an excellent pulpwood. The tree has the unusual property that fast grown wood has as good timber and pulping properties as slow grown wood. Silviculturally it is easy to establish, seeds plentifully from an early age and coppices well. Though frequently grown for firewood, the fuel quality is only mediocre.

The tree is tolerant of a wide range of climates and soils, but for fast growth and high production it needs a fairly high rainfall (1 750 to 2 000 millimetres is regarded as about the optimum) and a definite dry season. It also needs deep, well-drained soils for best results. Typical rates for production on good clay or laterite sites in the derived savanna zone in Nigeria are about 18 to 25 cubic metres per hectare per year in ten years. On poorer sandy sites it may be as low as 7 cubic metres per hectare per year. Higher rates of production are attained on high-forest sites. Generally speaking, rates of production fall off rapidly at lower rainfalls, i.e. below about 1 200 millimetres.

Except where conditions are most favourable, *Gmelina* is a short-lived tree. In Sierra Leone the experience is that where impeded layers in the soil restrict downward root development it does not survive more than about 15 years in plantations. In the same country, on young alluvium over river gravel, and also in the eastern Nigerian plantations on deep sandy loams it also survived much longer, though breast height diameter growth rates have fallen off after the eighth to tenth year in all cases. It is evident that soil conditions are of paramount importance wherever this tree is to be planted for timber production. It starts off rapidly on most soils but to maintain a high rate of growth to large size a deep, moist unimpeded soil is necessary.

The tree appears to be very responsive to nutrients, and is, for instance, stimulated to vigorous growth on the sites of old cattle kraals. For best growth it requires a high base status with ample available nitrogen. Fertilizer experiments might yield results of economic importance.

Gmelina has poor inherent bole form and it is necessary to plant closely and thin judiciously and heavily if straight timber or peeler logs are required.

Seed is abundant from the fourth or fifth year in plantations and has a high germinative capacity when fresh. Though plantations may be

formed by direct sowing the normal method is by stump planting. For details of establishment and management of plantations see Lamb, 1968.

Improvement of tree form by selection and breeding has been started and could have valuable results, but good silviculture may be even more important.

Pinus caribaea Morelet, *Pinus merkusii* Jungh & de Vries, and *Pinus oocarpa* Schiede

These tropical pines have been dealt with in more detail under Climatic type 4. In the humid tropical climate of type 5 they may be expected to grow even better, provided the most suitable provenances for the wetter climate are used and that they are planted on suitable soils. They should have a valuable economic role in derived savanna on deep sandy soils of low nutrient status too infertile for teak, *Gmelina* and the eucalypts.

Pinus kesiya Royle ex Gordon

This species, which has been discussed more fully in the previous section (p. 65), has done well in type 5 climatic conditions in Zambia at rather higher elevations (over 900 metres), where it is found to be more reliable than any other species of pine. It is worth including in any trials of pines at elevations between about 900 and 1 350 metres. At this higher limit it is possible that *P. elliottii* may be found as good or better.

Tectona grandis L.F. (Teak)

Teak is normally a plantation tree for high-forest types but, on account of its excellent and durable timber which fetches very high prices, it has been tried as an exotic on a wide variety of sites in almost every country in Africa south of the Sahara. Results have been very variable. It has been extensively planted in west Africa, e.g. in woodland-savanna in Ghana and in the derived savanna zone in Nigeria as well as in southern Sudan and to a much lesser extent in east Africa. In west Africa, mean annual increments of about 10 cubic metres/hectare/year have been recorded during the first 15 to 20 years of growth; in Tanzania a mean annual increment of 10 cubic metres/hectare has been recorded in a 45-year-old plantation on a high-forest site with 1 300 millimetres of rainfall (Wood, 1967). On savanna sites it has hitherto been grown mainly for poles, fuel and pit props, but is now being replaced to a great extent by *Gmelina* for these purposes on account of the more rapid growth and higher production of the latter.

Figure 20. Eleven-year-old *Tectona grandis* at Nimbia, Nigeria.

(*Courtesy* J.K. Jackson)

Teak is tolerant of a fairly wide range of climate. Given suitable soils, it will grow in the moister parts of Climatic type 4 but its optimum is around 1 250 to 2 500 millimetres of rainfall with a definite dry season of three to five months. It is very particular about soil and requires a deep, well-drained soil with a high base status. It does not grow well on clays or laterites or on shallow soils and the slightest degree of impeded drainage causes it to be stunted and unhealthy. It frequently starts off by growing rapidly but will soon check if conditions are at all unfavourable.

Provenance is also very important. There are very many unsatisfactory provenances with bad bole form, severe fluting, undesirable branching habit or a tendency to produce epicormic branches to an excessive extent. Some provenances are slow growing and unsuited to African conditions. The provenance planted in Trinidad, which is believed to have originated from Tenasserim, is of good growth and form and has been widely planted in Africa. Individual trees in it, however, vary considerably and it is now desir-

Table 8. — Summary list of species by climatic types

Climatic type	Species [1]	Method of establishment [2]
2. Subdesert (Annual rainfall 200-400 mm, 8-11 dry months in the year)		
Dependent on rainfall alone	*Acacia senegal*	DS
	Prosopis chilensis	DS (PP)
Dependent on irrigation, annual flooding or extraneous subsoil mixture	*Acacia albida*	PP (DS)
	Acacia nilotica	DS
	Azadirachta indica	St or PP
	Conocarpus lancifolius	St
	Dalbergia sissoo	St
	Eucalyptus camaldulensis	PP
	Eucalyptus microtheca	PP
	Eucalyptus tereticornis	PP
3. Dry tropical (Annual rainfall 400-1 200 mm but generally below 1 000 mm. Dry season 6-8 months)	*Anacardium occidentale*	DS
	(*Callitris* spp.)	PP
	(*Cassia siamea*)	St
	(*Dalbergia sissoo*)	St
	Eucalyptus camaldulensis	PP
	(*Eucalyptus citriodora*)	PP
	Eucalyptus microtheca	PP
	Eucalyptus tereticornis	PP

Climatic type	Species [1]	Method of establishment [2]
4. Semihumid tropical (Annual rainfall 1 000-1 500 mm. Dry season 4-5 months)	(*Acrocarpus fraxinifolius*)	St or large PP
	Araucaria cunninghamii	PP
	Callitris calcarata	DS or PP
	Callitris glauca	DS or PP
	Callitris intratropica	DS or PP
	Callitris robusta	DS or PP
	Cassia siamea	St (DS)
	Eucalyptus camaldulensis	PP
	Eucalyptus sp. 12 ABL	PP
	Eucalyptus citriodora	PP
	Eucalyptus cloeziana	PP
	Eucalyptus "grandis"	PP
	Eucalyptus pilularis	PP
	Eucalyptus propinqua	PP
	Pinus caribaea	PP
	Pinus kesiya	PP
	Pinus merkusii	PP
	Pinus oocarpa	PP
5. Humid tropical (Rainfall over 1 500 mm, 0-3 dry months)	*Acrocarpus fraxinifolius*	Large St or large PP
	Araucaria cunninghamii	PP
	Chlorophora excelsa	St
	Chlorophora regia	St
	Eucalyptus deglupta	PP
	Gmelina arborea	St
	P. caribaea	PP
	P. kesiya	PP
	P. merkusii	PP
	P. oocarpa	PP
	Tectona grandis	St

[1] Species in parentheses are occasionally used on specially favourable sites but more generally in the next moister climatic type.
[2] DS = Direct sowing. St = Stump planting. PP = Pot planting.

able to try to improve it further by selection and breeding from superior individuals, particularly from those which flower relatively late in life and therefore maintain an apically dominant leader for an adequate bole length.

Plantations are easily established by planting one-year stumps. The young plants are very susceptible to grass and weed competition and must be kept clean-weeded until canopy closes. A good burn of the regeneration area before planting is beneficial but in savanna the perennial grasses, which survive burning, must be eradicated. Taungya should be employed where practicable. In some areas it has been found that planting stumps in the dry ground some four to six weeks before the commencement of the rains results in greatly increased growth in the first year with negligible casualties, and this results in a consequent saving in weeding costs. The practicability of this varies from one locality to another and should be tested by experiment before general introduction. Being a strong light demander, early and regular thinning is necessary.

In view of the ease with which fast growing plantations of *Gmelina* and eucalypts can now be raised, the place of teak in savanna planting

has changed. Teak has no special merits as firewood, and its rate of production is inferior to the other species mentioned. On the other hand, teak as a pole sells much better than *Gmelina*. This makes a considerable difference to the economies of plantations. Both species need early and regular thinning, but teak thinnings can be sold whereas *Gmelina* thinnings often cannot.

One compelling reason for growing teak is its superb timber which often fetches prices several times as high as the general run of utility timbers. The best available sites should therefore be selected for teak and it is suggested that a site index at least 24 metres' top height at 50 years of age is about the minimum to be aimed at. Provenances with the best possible bole form should be used and they must be suited to the local climatic conditions. In order to produce high-class timber, the rate of growth should be so regulated that there are not less than 1.6 rings per centimetre (4 per inch) of radius. At rates of growth faster than this, the wood becomes brashy and weak. It may be difficult to avoid wider rings in the centre of plantation-grown trees but after the first few years it should be possible to contain the growth by judicious thinning to less than this figure, which is the equivalent of about 1.2 centimetres' diameter increment per year. Investigations at Dehra Dun, India, have shown that the timber strength does not vary significantly between 1.6 to 6.4 rings per centimetre (four and sixteen rings per inch), but over that figure it again becomes weaker owing to the pore rings being so close together. Therefore, if a plantation should check or become stagnant, the timber produced will be inferior in quality. Rotations long enough to reach good timber size will have to be used and experience in India with its long-established teak market is that there is a sufficiently steep price gradient for larger sizes to justify longer rotations than would be contemplated for less valuable timbers.

Other species

In addition to the species mentioned, numerous other species are being tried in derived savanna. The results of these trials will be of considerable significance as they hold out the hope of a solution to the problem of creating timber supplies quickly in the wetter parts of the savanna region. Unfortunately, the drier zones appear to be a much more intractable problem.

Part III

AFFORESTATION METHODS

8. SEED

General considerations

The procurement of adequate quantities of good quality seed of the species and provenances required is an obvious prerequisite for any programme of afforestation. In practice it is often difficult to find suitable and reliable sources for such seed supplies. Quantities available may be inadequate, the identification of the species or provenances may be unreliable or, through inadequately supervised collection, the seed may be taken from unsuitable trees, collected at the wrong time or stored under poor conditions, so that by the time it reaches the user it may have lost much of its germinative capacity. In order to be assured of receiving seed of the required identity and genetic constitution in good condition, it is necessary to establish contacts with reliable individual suppliers. Though not always possible, it would often be worth the expense, when importing seed of exotic species, personally to visit the countries from which the seed is to be imported, to inspect the actual sources for collection and to make arrangements with individual suppliers. International efforts to procure small samples of source-identified seed for provenance trials have been considerably expanded in recent years but as yet scarcely touch the problem of bulk supplies.

Usually the sooner this dependence on foreign suppliers can be replaced by local collection the better, as the forester then has complete control over the whole seed procurement process. It is also general experience that seed of an exotic species that has passed a generation in a new country becomes, by selection in plantation thinning and by choice of the best seed trees, much better suited to its new environment and grows better than seed from the same natural stands from which the original importation came.

Seed collection, treatment and storage methods are amply described in many textbooks and papers and it is not necessary to repeat them here. It is, however, appropriate to mention a few points which are particularly relevant to savanna afforestation.

Seed weights and viability

Table 9 (p. 78) gives the seed weight and indications of the average germinative capacity (GC) of the more important species used in savanna afforestation.

Pretreatment and handling

Pretreatment

A number of species require special pretreatment of the seed if satisfactory germination is to be obtained. Such treatment may consist of soaking in water for varying lengths of time, alternate soaking and drying, scarifying or chipping the seed coat to render it permeable to water, plunging the seed into boiling water or even boiling it for a short time, or soaking it in concentrated sulphuric acid. The aim is not only to get a high final germination percent but also rapid and uniform germination after sowing.

Soaking in concentrated sulphuric acid is a common treatment for the hard-seeded acacias and some other species. As this chemical is dangerous to handle and, when mixed with water, produces a violently exothermic reaction, a note of warning on its use is appropriate. *Never add water to the acid* or it may boil explosively and splash the operator causing skin burns or, if it gets in the operator's eyes, blindness, quite apart from damage to clothing, etc. If a dilute mixture has to be made with water, always trickle the acid into the water slowly, stirring continuously, and pause if the mixture gets dangerously hot.

TABLE 9. — SEED WEIGHTS AND GERMINATIVE CAPACITY OF PRINCIPAL SAVANNA AFFORESTATION SPECIES

Species	Number of seeds		Remarks	References
	Per lb	*Per kilogramme*		
Acacia albida	5 000	11 000	GC high for treated seed	Giffard, 1966 Parry, 1956
Acacia nilotica (Syn. *A. arabica*)	3 500 to 4 000	7 700 to 8 800	GC very high and germination time only 2 days for treated seed	Parry, 1956
Acacia senegal	3 250	7 150	High (usually untreated)	Parry, 1956
Acrocarpus fraxinifolius	14 000	31 000	Fairly high GC after treatment	Parry, 1956
Anacardium occidentale	70	154		Parry, 1956
Araucaria cunninghamii	1 200 to 2 000	2 700 to 4 400	GC high when fresh and if collected when just ripe. Loses viability in a few months unless refrigerated	Ntima, 1968
Azadirachta indica	1 800	4 000	GC low unless very fresh. Fruit pulp must be removed after collection	Goor and Barney, 1968
Callitris calcarata (Syn. *C. endlicheri*)	70 000	154 000	GC high	Gerber, 1971
Callitris glauca (Syn. *C. huegelii*)	32 000	70 000	GC 30-40 percent	Turnbull, 1972-73
Callitris intratropica	54 000	120 000	GC 5-20 percent	Turnbull, 1972-73
Callitris robusta (Syn. *C. preissii*)	45 000	100 000		Parry, 1956
Cassia siamea	17 000	37 400	GC very high	Parry, 1956
Chlorophora excelsa	200 000	440 000	GC high when fresh	Parry, 1956
Chlorophora regia	—	—	Understood to be similar to *C. excelsa*	
Conocarpus lancifolius	Up to 772 000	Up to 1 700 000	GC about 25 percent	Boaler, 1959
Dalbergia sissoo	20 000	44 000	GC high	Parry, 1956
Eucalyptus camaldulensis (Syn. *E. rostrata*)	334 400	763 000	Uncleaned, viable seeds	Turnbull, 1972-73
Eucalyptus citriodora	52 800	116 000	Uncleaned, viable seeds	Turnbull, 1972-73
Eucalyptus cloeziana	64 000	141 000	Uncleaned, viable seeds	Turnbull, 1972-73
Eucalyptus deglupta	2 560 000	5 632 000	Uncleaned, viable seeds	Turnbull, 1972-73
Eucalyptus grandis (from Australia)	288 000	634 000	Uncleaned, viable seeds	Turnbull, 1972-73
Eucalyptus microtheca	190 400	419 000	Uncleaned, viable seeds	Turnbull, 1972-73
Eucalyptus pilularis	24 000	53 000	Uncleaned, viable seeds	Turnbull, 1972-73
Eucalyptus propinqua	193 600	426 000	Uncleaned, viable seeds	Turnbull, 1972-73
Eucalyptus saligna (from Australia)	256 000	563 000	Uncleaned, viable seeds	Turnbull, 1972-73

TABLE 9. — SEED WEIGHTS AND GERMINATIVE CAPACITY OF PRINCIPAL SAVANNA AFFORESTATION SPECIES (*concluded*)

Species	Number of seeds		Remarks	References
	Per lb	*Per kilogramme*		
Eucalyptus tereticornis				Turnbull, 1972-73
New South Wales	188 800	415 000	Uncleaned, viable seeds	
Queensland	361 600	796 000	Uncleaned, viable seeds	
Victoria	139 200	306 000	Uncleaned, viable seeds	
Papua, New Guinea	134 400	296 000	Uncleaned, viable seeds	
Gmelina arborea	320 to 640	700 to 1 400	Cleaned nuts. GC high but loses much of its viability if stored for a year	Parry, 1956
Pinus caribaea var. *hondurensis*	23 600 to 36 300	52 000 to 80 000		Lückhoff, 1964
Pinus kesiya (Syn. *P. insularis, P. khasya*)	25 000 to 28 000	55 000 to 62 000		Parry, 1956
Pinus merkusiana	12 700 to 19 000	28 000 to 42 000		Cooling, 1968a
Pinus merkusii	26 300	58 000		Cooling, 1968a
Pinus oocarpa var. *ochoterenai*	18 600 to 24 900	41 000 to 55 000	Viable seeds	
Prosopis chilensis	4 000 to 7 000	8 800 to 15 400		Parry, 1956
Tectona grandis	400 to 900	880 to 2 000	Stores well. GC 25-50 percent, may be higher after one-year storage	Parry, 1956

In treating seed, use about 12 litres of concentrated acid to 10 kilogrammes of seed. After soaking for the prescribed time, drain off the acid thoroughly (the acid can be used again) and tip the seed into a large quantity of water for its first rinse. Wash thoroughly with several changes of water until it is safe to handle. As an antidote against accidental splashes a concentrated solution of sodium or potassium bicarbonate should be kept handy.

The following species need, or at least benefit from, pretreatment of the seed before sowing.

Acacia albida

Soak seeds in water for 48 hours before sowing (Congo) or soak in concentrated sulphuric acid for 20 minutes (Nigeria).

Acacia nilotica

Soak in concentrated sulphuric acid for 60 to 80 minutes. Germination is then very rapid, occurring in about two days.

Acacia senegal

Often sown without pretreatment but soaking for 40 minutes in concentrated sulphuric acid has been found beneficial (Fishwick, 1966).

Araucaria cunninghamii

Though sown direct without treatment in New Guinea, in Nigeria it has been found preferable to pregerminate it in moist sterilized sand or vermiculite and to prick out the germinating seeds into polythene pots.

Chlorophora excelsa and *C. regia*

Seed is extracted from the mulberry-like fruit by soaking and squeezing under water. Extraction is not essential if sowing can be done at once with macerated fruit but seed cannot be kept more than a few days in the fruit, as fermentation will occur.

Pterocarpus angolensis

The fruits require chipping at one edge to allow penetration of water.

Unweathered teak seed germinates slowly and irregularly, a large proportion often taking over a year to appear. The seed is adapted to remain viable on the ground for long periods and to germinate, often some years later, after prolonged weathering or after a forest fire. In order to get rapid and more uniform germination, many different treatments have been used such as scarifying, burying in termite mounds, burning straw over the spread seed, scorching lightly with a flame gun, etc. All of these are effective to some degree. The method most generally used, however, is to spread the seed out on a hard surface in the sun in a layer about 5 centimetres deep and to soak it thoroughly. Then, turning it over from time to time, allow it to dry out and bake in the sun for a day or two. This process of alternate soaking, drying and baking is repeated a number of times, usually between five and ten cycles, until signs of germination appear. Each cycle of wetting and drying may be one day for soaking and three to five days for drying and baking. As soon as germination has started, the seed should be sown in the nursery, covered thinly with soil, and watered thoroughly. The pretreatment process should be timed so that sowing takes place shortly before the main rains are expected to break.

Teak seed of different provenances may differ greatly in the amount of pretreatment required to break dormancy. Seed from high rainfall areas with a moist climate usually requires less treatment than seed from dry hot areas.

In Sudan good results have been obtained by collecting seed that has lain on the forest floor throughout the rains and stratifying it in pits in the nursery with alternate layers of organic material, seeds and soil. The pits are usually 2 metres long by 1 metre wide, and 1 metre deep. The pile is watered daily for about 10 days, after which the seed is ready for sowing (Wunder, 1966a).

In Tanzania teak seed which has been collected from the ground under seed trees and which has preferably been stored for 8 to 12 months, is soaked for 72 hours in full sacks in a stream or in 44-gallon (about 166-litre) drums. It is then sown at the rate of 5 kilogrammes per square metre and, after two days in the sun, it is covered with about 2.5 centimetres' depth of soil, and is watered daily (Wood, 1967).

Seed storage

In the list given on p. 78-79 those species mentioned as having short viability should be sown fresh and no attempt made to store them from one season to the next. During the period between collection and sowing, in general seed should be sun-dried and stored in a cool dry place at as constant a temperature as possible. Any fleshy fruits must have the pulp removed immediately after collection or it will ferment and ruin the seed. Fatty or oily seeds are usually very perishable and may retain their viability for only a few days in some cases. They cannot be stored and must be used immediately.

The hard dry types of seed typified by *Acacia* and *Prosopis* spp. usually keep well. They should be thoroughly dried in the sun and stored in airtight tins in a cool place. If there is any danger of insect attack some DDT dust should be shaken up with the seed in the container. Seed of the pines should be similarly stored but, if required to last from one season to another, the seed should be dried to 6-10 percent moisture content and the containers should be kept at a constant controlled temperature of 3 to 5°C. *Araucaria* seed is very perishable; in Papua and New Guinea fresh seed of *A. hunsteinii* is placed in plastic bags with moist blotting paper and a dusting of Cuprox and sealed in airtight cans kept at 5°C (Nash, 1970). Even then it should be used as soon as possible. Teak seed is unusual in that, if properly stored, it normally germinates better in the second year after collection. The seed should be dried in the sun and stored in sacks hung up in a cool place.

Seed handling

A check should be kept from time to time on the germination capacity of the seed in storage. In determining quantities to be issued, allowance must be made, not only for the germination percent of the seed tested in a germination apparatus, but also for the anticipated plant percent, i.e., the number of plants fit for planting that are expected to be produced under nursery conditions from seed of a given germination capacity in the laboratory. This may have to be guessed to start with but it is important to collect data as experience of the behaviour of the various species in the nursery is gained.

9. GROUND PREPARATION

General considerations

Savanna conditions, involving as they do shortages of water available for the growth of planted trees at some periods of the year, demand more intensive and thorough ground preparation than would be considered necessary for afforestation in moister climates. The objectives in ground preparation in savannas are:

1. To remove all competing grass and tree growth from the site, which should be as nearly clean as possible.
2. To create conditions which will enable the soil to catch and absorb as much of the rainfall as possible. Surface run-off must be reduced to a minimum. The aim is to build up deep reserves of moisture in the soil.
3. To provide good rooting conditions for the trees and as large a volume of rootable soil as possible. Where there are hard pans, plinthite layers or indurated horizons near the surface, these must be broken up.
4. To leave conditions where mechanized tending operations can be carried out in the establishment stage after planting; this usually requires the removal of all tree stumps.
5. To create conditions where the danger of fire is eliminated or at least minimized.

These objectives are directed toward giving the young trees a good start with rapid early growth and freedom from check. They apply to all savanna conditions, though the methods used to achieve them will vary considerably according to the type of savanna, the soil conditions, the vegetation, the rainfall and its distribution, the presence or absence of indurated or impermeable horizons in the soil, the need for protection against desiccating winds, the scale of the operations and the value of the crop to be grown as determining the amount of money that may be justifiably spent on establishing plantations. Ground preparation together with post-planting tending form the biggest block of expenditure in the total establishment cost; and they are linked inasmuch as inadequate site preparation can increase subsequent tending costs out of all proportion to any initial savings.

Ground preparation may be either by hand or mechanical means. Hitherto the former has been more common, but the latter is coming into increasing favour for large schemes and has become normal practice in many areas. This is partly because the supply of labour and the time available for ground preparation (and subsequent cultivation) in the savanna region are both too small to permit large-scale projects to be undertaken by hand, and partly because heavy clearing of woody growth and dense, tall grasses is usually much cheaper by machines, provided the scale of operations is large enough and the machines used are powerful enough to do the job efficiently. Certain operations such as deep subsoiling and the breaking up of pans and plinthite layers can only be done by machines. On the other hand, the preparation of ridges and furrows and the creation of clean weed-free conditions, while physically feasible by hand methods, can, in the case of some large schemes, only be completed in the time available by machines.

Manual methods

Preparation of the site by hand is, thus, only possible and economic for relatively small-scale projects where the labour of clearing the growth and of working the soil is not too heavy and time consuming. Under savanna conditions partial clearance by strips or patches is rarely successful owing to the competition of the remaining growth for the limited available moisture, and complete clearance, especially in the more arid types, is usually necessary. Burning of the cleared brush, grass and other debris is also necessary if intensive plantations are to be raised. Where there

is a local demand for charcoal sufficient to encourage burners to collect and burn the slash and to sell the charcoal produced, some saving in the cost of site preparation may be effected. In Zambia a certain proportion of the clearing debris is always disposed of by charcoal burning, but the amounts involved will remain small until kilns are introduced.

Soil preparation can be either in patches or strips, or by complete cultivation, but hand working is usually too expensive to contemplate for complete cultivation, unless practised in conjunction with taungya. But land hunger is generally insufficient in the savanna region to make taungya practicable on any scale; it seems to be mostly limited to the derived savannas in west Africa. Animal-drawn ploughs and harrows may be economic for small-scale operations in certain conditions.

Nevertheless, for some species such as the various eucalypts, *Cassia siamea* and teak, which are highly intolerant of competition from grass, weeds and woody growth, complete ground preparation is essential. For certain other species such as pines and *Callitris*, spot preparation may be sufficient, but the spots should be adequately large (1 to 1.5 metres in diameter) and it is important that the work is done thoroughly.

Other methods of ground preparation by hand that merit attention are the " citemene " or " rab " methods, " tie ridging," and for more hilly ground, contour trenching.

The "citemene" technique

This is similar to the " rab " method of India. Briefly it consists of piling the lop and top, which results from harvesting or clearing the land, into long lines or stacks. After drying out, these are burnt and seed is sown or plants planted in the resultant ash patches. The advantages of this method are that the burn kills off all weed growth and the surface population of termites, with the result that the area keeps free from weeds for an appreciable period and the ash provides a useful fertilizer for the plants.

This technique was formerly practised in Zambia for forming eucalypt plantations in " miombo " woodland that had been harvested for charcoal, but has been largely abandoned there because of the difficulties in carrying out the burn in time over large areas, and in protecting the young crop from fire. The latter arises because, at the spacings for the burnt spots (old charcoal burns) practised there, the young crop was growing up in a matrix of coppicing " miombo." In consequence, plantations on fully cleared ground are now favoured in Zambia.

In Zambia, results were best when seed was sown on the ash resulting from charcoal burning. Sowing on the fine ash resulting from fierce burns of dry brushwood gave very erratic results because the ash, being so fine, was often washed away by the rains and in times of drought gave little or no surface protection to the seedlings. The ash from charcoal burning, being heavier and more porous, was less liable to be washed away and had a better mulching effect.

The beneficial effect of burning on the growth of seedlings or plants has long been appreciated and a " good burn " over the plantation area is regarded as highly desirable for less specialized ground preparation techniques than " citemene." There is still some doubt whether the effect is mainly physical or chemical. Undoubtedly the sterilization of the soil from weed seeds is important and the effect of a burn can be largely reproduced by complete removal of weeds on an unburnt area. Claims are also made that the manurial effect of the ash is the principal cause of the better growth on burnt over areas. Experiments in Nigeria with *Eucalyptus " saligna "* (probably a hybrid, see p. 61) planted on cleared savanna woodland showed that growth was strikingly better on spots where slash had been burned. Measurements after one year's growth showed heights of 4.6 to 5.2 metres on the burnt patches as compared with 1.8 to 2.7 metres on nonburned soil. The calcium, magnesium and pH values in the burnt over soil were much higher than in the unburnt area. It is probable that both the manurial effect and the sterilizing effect play a significant part in causing the accelerated growth. Burning of the slash should therefore be done over as extensive an area as possible but, where not possible, more intensive soil working and clean weeding will largely compensate for the lack of a burn.

" Tie ridging "

This was originally an agricultural practice which was adapted for raising *Cassia siamea* by direct sowing in Tanzania. In this method the whole of the area is cultivated and then ridges are built up at intervals by hoeing. The main

ridges are aligned along the contours and are joined (" tied ") by smaller ridges at right angles, the effect being to create a series of shallow, more or less square basins, bounded by the ridges, which hold the rain and prevent erosion. The ridges are generally about 3 metres apart. The seed is sown on the ridges. This method has given very good results in Tanzania and can be combined well with traditional methods of raising agricultural crops. It is suitable for flat or gently sloping ground.

Contour trenching and terracing

In hilly country, various forms of trenching or terracing along the contours are used in site preparation for planting. The trenches may be continuous, they may be divided into sections by cross banks or they may consist of short, discontinuous lengths of trench so arranged that the gaps between the trenches in one row are opposite the trenches in the next row so as to catch any run-off of rainfall down the hill slope. Trenches are usually made by hand. Terraces which are wider and flatter may be either hand made or bulldozed out of the side of the hill. The bottom of a terrace is usually made to slope into the hillside. Sowing or planting is done either on the ridge of thrown up soil, at the base of the ridge or in worked up patches in the bottom of the trench or terrace according to moisture conditions. Trenches and terraces have the triple function of catching run-off of rainfall, checking erosion and providing favourable soil conditions for planting or sowing. They are widely used on moderate to severe slopes throughout the arid and semiarid areas of the world and there is an extensive selection of literature on the subject which may be referred to for details (Ahmad, 1962; Bhimaya and Kaul, 1960; Bhimaya *et al.*, 1963; Goor and Barney, 1968; Goswami, 1960; Kaul, 1970; Nash, 1968). Over most of the savanna the gentle topography makes terracing and trenching unnecessary.

Mechanical methods

The recent introduction and development of heavy machinery for clearing, ground preparation and later tending have made it possible to undertake afforestation on sites hitherto uneconomic to prepare manually and on a scale and with an efficiency formerly unattainable. Provided that the scale of operations is large enough to keep a balanced fleet of heavy and light tractors, " stingers " (see below), subsoilers, ploughs, dozers and harrows adequately employed throughout the year, large areas can be dealt with at a relatively low cost per hectare. The methods used and the machines employed vary with local conditions. The following notes are illustrative of two main types of savanna afforestation. More detailed information is to be found in Deveria, 1972; Nash, 1968; and Catinot, 1965.

Savannas of Congo

The soils are sandy or heavy clays and carry a vegetation of tall and dense grasses in which there is scattered tree growth. The rainfall is 900 to 1 600 millimetres. Groulez, 1967e, describes the procedure for ground preparation as follows.

Shrub and tree growth is dealt with by a track-laying tractor fitted with an undercutting blade. This is done between July and the following February and the debris is burnt in July. Tall grass clumps are dragged out of the ground by towing a heavy bar behind the tractor and burnt after a short period of drying. On the heavy clays the soil is first worked to a depth of 25 to 30 centimetres by a disc plough and subsoiled at right angles to a depth of 50 to 60 centimetres at a spacing of 1.4 metres between runs. This is followed by ploughing, either in one direction only or in two directions at right angles, according to the density of the regrowth of weeds. On the lighter sands, sometimes a deep soil discing is followed by harrowing, or sometimes subsoiling is followed by ploughing.

The costs (rounded) per hectare of ground preparation were as follows in 1966:

	CFA francs	*U.S. dollars*
Clearing woody growth and burning	6 900	28
Destruction of grasses and weeds	1 500	6
Deep working	9 200	37
Subsoiling at 1.40 metres spacing	7 200	29
Cleaning up	700	3
Total	25 500	103

This is about 50 percent of the total cost of establishing eucalypt plantations including nursery costs, planting and tending for three seasons. (The ground preparation costs include direct costs, local supervision, depreciation on machines, etc., but not general overheads.)

Savanna woodland

In the more densely wooded vegetation type of savanna woodland (rainfall 900 to 1 400 millimetres per year) the techniques used are somewhat different owing, in the main, to the heavier woody growth that has to be cleared. The following account of current methods used in the "miombo" woodland of Zambia is based on several recent papers from that country (Allan, 1967a; Allan and Endean, 1966; Deveria, 1972).

Land suitable for plantations is generally logged for mining timber and smelter poles prior to land clearing operations, but this removes only a small volume, and between 90 and 125 cubic metres (solid) per hectare of indigenous woody material remain to be disposed of.

The sequence of land clearing operations — knocking down (see below for description), windrowing, cleaning up, ploughing and discing — should all be completed within the twelve-month period immediately preceding planting. The early use of cleared land reduces the weeding intensity immediately following planting. The sequence is:

January-April:	Knock down. Ideal unit is two D-8s with anchor chain plus two D-7s with pusher bars.
May onward:	When ground becomes fairly dry, windrow and remove any stumps between windrows. Plough between windrows.
August-September:	Burn. Restack between windrows and remove stumps from original windrows. Restacking and tidying up is done by D-7s or D-8s with root rakes.
October-December:	Reburn. Anything which cannot be burned is piled on anthills. Complete ploughing and discing prior to planting. Experiments are being carried out with a rear-mounted rake on the D-7s or D-8s which gleans and reharrows in one operation leaving ground clean enough for planting.

"Knocking down"

This is the operation in which the indigenous woodland is felled and partially stumped. It is best done in January to March when the soil is moist and the trees are more easily pulled out by the roots. In drier weather there is a tendency for the stems to snap, leaving stumps and roots to be extracted by hand at some considerable cost.

Knocking down is done on contract by land clearing units. A land clearing unit comprises two standard Caterpillar D-8 tractors fitted with protective canopy and covers and one D-7. Two of the tractors (D-8s) pull an anchor chain of 70- to 80-millimetre links not less than 50 metres long, with at least two swivels fitted near the towing tractors.

The towing tractors advance through the bush some 9 to 15 metres apart (depending on the density of the bush) and the chain knocks down all the large woody vegetation in a swath. A group of trees or an exceptionally large trunk can halt the chain and it is the function of the third or "stinger" tractor to assist in removing such snags. The "stinger" is a metal arm mounted on the front hydraulics of the tractor and is used to push down any large trees resisting the chain; by applying the full pressure of the stinger at a point some distance up the trunk, all but a few exceptional trees are felled. No time is wasted on exceptionally large trees which may prove time consuming and costly to remove and the chain is slipped round such stubborn obstructions. Occasionally a second "stinger" tractor is attached to a unit and this speeds up progress. Tractor sweeps should be as long as possible and very often exceed 1.6 kilometres (1 mile). Output, which depends on a number of conditions and factors, is of the order of 30 to 40 hectares per unit per 12-hour day.

Windrowing

After knocking down, and when the ground is sufficiently dry, the woody material and debris is windrowed by bulldozing into linear heaps approximately 40 metres apart. This work is done by the land clearing unit D-7 tractors, with mounted blades.

Cleaning up

Following windrowing a mainly hand-labour cleaning operation is necessary. This operation involves digging out and removing all roots and stumps over 7.5 centimetres' diameter within 45 centimetres of the surface. In removing larger stumps left mainly after logging, medium wheeled tractors with winches assist the hand operations. Surface debris is gathered and stacked and stump holes are filled in. In a windrowed area the land between the windrows is cleaned and the debris is added to the windrows, which are usually burnt in the dry season between July and October. In cleared areas the debris is usually stacked or bunched for burning, but the larger noncombustible pieces are dragged or winched and deposited on anthills. It is difficult to organize, supervise and set standards for this cleaning up operation, and there is much room for improvement.

Laying out

When the land is clear, prior to ploughing, the plantation layout is pegged, beaconed and surveyed. Main roads are put in, and on this is superimposed a pattern of blocks of about 400 hectares and compartments of approximately 40 hectares, with access roads and fire lines. Following ploughing, certain specified roads are cambered to allow ready access for planting operations.

Ploughing and discing

Ploughing is to a depth of 20 to 25 centimetres and should be done during May to July to achieve a bare fallow over the remainder in the dry season. On certain areas the heavy weed growth is burnt off between June and September, ploughing following during July to October. Main ploughing is by large 96 hp wheeled tractors dragging heavy five- or six-disc ploughs. The average output is 0.8 hectares per hour. The ploughing of newly stumped land is hard on tractors and equipment, and experiments continue with more robust equipment than the present range.

Discing follows ploughing and if possible should be done within a seven-day period prior to planting, to allow stock to be planted into a relatively level and weed-free site. Discing is by large wheeled tractors dragging a 20-centimetre heavy duty harrow with cut-away discs. An output of some 1.4 hectares per hour is the average; considerably higher outputs are possible but the damage to the implements is excessive. Medium tractors with matched harrows supplement the heavier equipment when necessary.

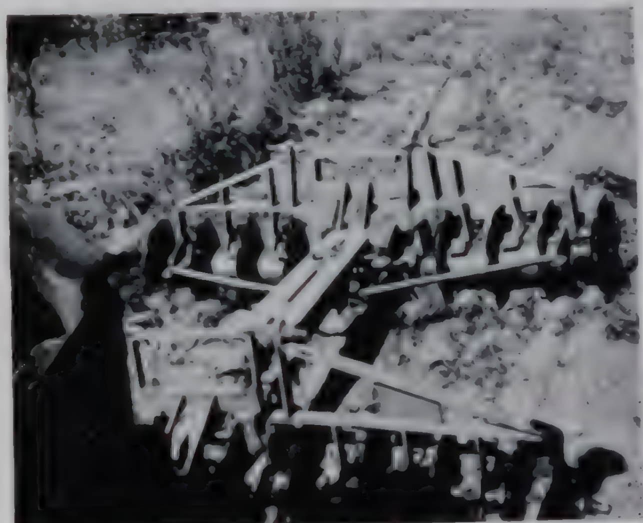


Figure 21. Rome ploughs in tandem used for site preparation in Zambia.
(*Courtesy* Forest Department, Zambia)

In the derived savanna zone of Nigeria, a pilot plantation project of 160 to 200 hectares a year has been started at Nimbia (Barrott, 1969). In this, Caterpillar D-4 (70 hp) tractors are used for clearing. Trials showed that trees up to 25 centimetres in diameter can be pushed over with the bulldozer blade without digging the roots; the rate is about 0.3 hectares per hour. Larger trees needed about 20 minutes per tree for digging and pushing, while trees over 70 centimetres in diameter had to be cleared by hand. The total costs of combined tractor and hand clearing amounted to $90 to $108 per hectare on the limited scale of operations at present being undertaken. This is roughly the same as the cost of clearing by hand. The use of more powerful

tractors and of supplementary equipment to reduce the cost of clearing large trees is indicated, though it may be necessary to work to a bigger annual area programme to make it economic.

Windrowing is also done by D-4 tractors and the same machines are used for ploughing, drawing "Rome" disc ploughs having loadings of 250 kilogrammes per disc. These give similar penetration (20 to 25 centimetres) to that achieved in Zambia. The rate of ploughing is about 0.5 hectares per hour. The final disc harrowing is done shortly before planting. Wheeled tractors are used and the rate of working is about 0.8 hectares per hour. Faster rates could be achieved but only at a high cost of wear and damage to the implements.

Detailed costings for this project (based on 1968 operations over 120 hectares) have been worked out. The area cleared had a larger proportion of big trees and denser stands than average for the sites available for planting. On a sample area containing 245 trees/hectare, 66 percent were in the 7.5- to 15-centimetre diameter class, 19 percent in the 15- to 22.5-centimetre class and 5 percent in the 22.5- to 30-centimetre class. The cost of clearing and site preparation was as follows:

	U.S. dollars per hectare
Clearing	87
Windrowing	28
Burning	2
Additional clearing	6
Pioneer ploughing	21
Disc harrowing before planting	5
Total	149

This does not include local overheads of about $38 per hectare.

Costs of ground preparation will vary considerably from site to site and would be appreciably less in areas with smaller trees and less dense stands. Costs would also be reduced if the scale of planting were sufficient to allow the use of heavy machinery, as indicated by the low cost of "knocking down" — $26 to $28 per hectare for clearing the denser "miombo" woodland in Zambia by the methods already described.

Important lessons learned so far are:

1. If machinery is used, it must be powerful enough to do the job efficiently and completely, with a margin of power in hand so that it is not held up. Wear and damage are less if the machinery is not working near the limit of its capacity.
2. If anything holds up mechanical operations it may pay to introduce supplementary equipment (e.g. an extra tractor with a "stinger" for the quick elimination of large trees).
3. If a job can be done by a wheeled tractor instead of a track-laying tractor, the former will be much cheaper but again it must be powerful enough to do its job easily and quickly.

The D-7 and D-8 Caterpillars used in Zambia are typical of what is required for their particular jobs. D-4 Caterpillars are not powerful enough, except in light vegetation or on easy soils.

The above accounts of clearing and preparing the site have been given in some detail, as they illustrate different approaches to the problem of creating the conditions for planting mentioned at the beginning of this section.

10. DIRECT SOWING

The attractions of direct sowing are its cheapness; it eliminates nursery costs and all the trouble and labour of raising plants and of planting them. It is, however, usually much less reliable and is only justified with species and in conditions in which:

(*a*) seed is plentiful and cheap;
(*b*) adequate germination under field conditions can be relied on;
(*c*) the seedlings rapidly send down a deep tap root and are able to withstand adverse climatic conditions in the weeks and months after germination;
(*d*) the rate of growth of seedlings from direct sowing is sufficiently fast to make a prolonged period of tending and weeding unnecessary; otherwise the financial advantage of direct sowing is lost.

Savanna conditions are in general harsh and unfavourable for seedling establishment and it is only rarely that direct sowing is sufficiently reliable to be worth contemplating.

The most notable examples of direct sowing under savanna conditions are in raising plantations of *Acacia nilotica* and *Acacia senegal* in Sudan. In both cases the usual method is to sow in spots or lines after clearing and cultivation either by hand or mechanically, and to keep the plantations clean weeded until the young trees are above the grass. Recent experiments comparing different methods of soil preparation for the direct sowing of *Acacia senegal* on the clay plains of Sudan have conclusively shown that the cheapest and most successful method is to dig out pits 30 × 30 × 30 centimetres, break up the soil which is returned to the pit and sow the seed in the loosened soil. The timing of the sowing is important, i.e. early July, which is a week or two before the main rains are expected. The importance of timely weeding and soil working is stressed (Waheed Khan, 1966b).

While pit sowing of *Acacia nilotica* is successful on the clays of eastern Sudan, it is necessary to sow on mounds on the clays of the Upper Nile where the rainfall is heavier and waterlogging is liable to occur. If conditions are suitable, sowing on mechanically prepared ridges has now replaced mound sowing. Other species which are sometimes raised by direct sowing are *Cassia siamea, Azadirachta indica, Gmelina arborea* and *Anacardium*. For an account of *Anacardium* sowing in Senegal see p. 48.

In Tanzania normal practice is to line-sow *Cassia siamea* along ridges, preferably "tied ridges," 2.5 to 3 metres apart, after thorough soil cultivation. The sowing rate is 2 to 3 kilogrammes per hectare, giving an average spacing of about 10 centimetres between seeds in the rows. Sowing is done at the beginning of the rains. Germination is usually good, but any gaps should be resown early in order to obtain full stocking. When the trees are 1 to 1.5 metres high (6 to 12 months after sowing) spacing is increased to 2.5 to 3 metres in the lines by uprooting (*not* cutting back) the surplus plants. Clean weeding during the first year is essential to obtain early vigorous growth (Parry, 1954). At one time some of the eucalypts, notably *E. citriodora, E. camaldulensis* and *E. tereticornis*, were direct sown in Zambia with considerable success, but this has now been entirely superseded by the planting of tubed stock.

With regard to timing, the usual practice is to sow early in the rains or just before if possible. Where the onset of the rains is accompanied by heavy storms, however, late sowing after these have passed generally gives better results. This has been confirmed by experience in Zambia.

Weeding of direct sowings

For most species several weedings a year are necessary. In Sudan, for example, the usual

practice for *Acacia senegal* is to weed twice in the first year and once or preferably twice in the second. Weeding is done with disc harrows where available and no special measures are taken to keep the harrows clear of the young plants, as the latter have been found to stand up well to disc harrowing. Clean weeding is the usual practice but line and spot methods are occasionally adequate for species that are tolerant of weed competition.

Wherever the availability and cost of seed are serious limiting factors, planting is generally preferred to direct sowing. Furthermore, as genetically improved seed becomes available in small quantities, the need to plant so as to make the best use of the seed will become all the more desirable. It is, however, important not to overlook the advantages of direct sowing techniques, particularly as in some countries there have been considerable recent developments in techniques (Derr and Mann, 1971). These include the availability of repellants and of methods of pelleting the seed with a coating containing hygroscopic materials, nutrients and repellants. Broadcast sowing of such treated seed from aircraft on to cultivated ground enables large areas to be afforested relatively cheaply, i.e. at a cost of about one third to one half of that of planting. But, to be successful, the conditions mentioned at the beginning of this chapter must be fulfilled.

11. NURSERY PRACTICE

General considerations

Planting is by far the commonest method of making plantations in the savanna. The reason for this is that, although somewhat more laborious and initially as a rule more expensive than direct sowing, it gives the plantation a better start, provided that sturdy and vigorous planting stock is used. Casualties are fewer, early growth is faster and establishment quicker; this results in a saving of weeding costs. In harsh or marginal conditions these advantages are usually decisive. The establishment of a well-sited and efficiently run forest nursery can be considered an essential prerequisite for any savanna afforestation project. Nurseries should be sited on level, well-drained sites convenient to the planting area with access to sufficient quantities of good quality water and soil.

The elements of good nursery practice are described in numerous textbooks and papers and apply as much to savanna as to high-forest conditions. There is, therefore, no need to repeat them here, and comments will be confined to matters specifically relating to savanna planting.

In the summary table of species grown in the various climatic types on p. 72, indications are given of the method and kind of stock used in forming plantations. By far the majority of species are now raised as potted plants in polythene pots in the nursery. A few are sown direct (see Chapter 10). *Acrocarpus fraxinifolius* is sometimes planted as big "striplings" (nursery-grown saplings that are stripped of all foliage and branches, save for a few apical leaves, and sometimes root-pruned, before planting out) but the tendency is now to raise large plants in polythene pots. Some species are raised as "stumps" (root and shoot cuttings) in nursery beds, and where stump propagation is reliable, it is the preferred method, as it is usually cheaper overall and less trouble. The majority of species, however, do not grow readily from stumps and have to be raised as potted stock.

Polythene pot method

For savanna planting, which so often entails planting under adverse conditions of soil and climate, the most common practice is to raise plants in polythene pots or tubes. Formerly balls of earth or earth blocks were used, and still are used to a limited extent, as well as tubes of other materials such as clay, metal, bamboo, banana leaves, cardboard, waterproof paper, etc., but these are either more expensive or less convenient than the polythene pot or tube, especially for big afforestation schemes requiring very large numbers of plants. Polythene pots have the advantages of being cheap, light and easy to handle and experience over a great range of savanna

FIGURE 22. Pine seedlings in polythene pots at Samaru, Nigeria. The painted strips on the black polythene are of different colours to distinguish between different provenances and species during transport and at planting.

(*Courtesy* J.K. Jackson)

conditions has shown that they give appreciably better results than any other method of comparable cost.

Size and type

The polythene used for pots or tubes is usually from 150 to 250 " gauge " (a thickness of 0.0015 to 0.0025 inches = 0.0375 to 0.0625 millimetres or 37.5 to 62.5 microns) and may be black or transparent. The black is often preferred as it is more durable and gives less growth of algae in the pot. It has the disadvantage of getting hotter than the transparent polythene but lethal temperatures have not been found to develop in black containers even during the hot season (Iyamabo, 1967).

The size of pots used varies according to the species being raised and the time required to raise them to planting size. A common size for eucalypts and pines is 25 centimetres' circumference (i.e. 12.5 centimetres " lay flat ") and 20 to 25 centimetres long. Bearing in mind that a 25-centimetre-long pot of this circumference will contain up to 1 200 cubic centimetres of soil weighing about 1.8 kilogrammes and that transportation of pots from the nursery to the planting spot is a major item of expenditure, the practicability of using smaller pots is being actively investigated. Experiments in northern Nigeria, for instance, on the use of different pot sizes for *Eucalyptus camaldulensis* showed the following differences in the growth of plants at the end of the first season after planting out in the forest.

Table 10. — Effect of pot size on height growth of *Eucalyptus camaldulensis*

Pot size	Circumference		Length		Approximate soil weight		Height growth	
	In.	*Cm*	*In.*	*Cm*	*Oz*	*G*	*In.*	*Cm*
Large	10	25	10	25	64	1 800	80	203
Medium	10	25	6	15	38	1 075	70	178
Small	6	15	6	15	14	390	57	145

Much of the difference in growth took place in the pots in the nursery. The very material saving in the volume and weight of soil that had to be transported is notable (Jackson and Ojo, 1970). In the field, pots 15 centimetres long by 25 centimetres' circumference have been found to give satisfactory results for pines and eucalypts in the Guinea zones. Pots 15 centimetres long by 15 centimetres' circumference gave much higher mortality with pines.

In Zambia, where the standard size of polythene pot was formerly 25 centimetres' circumference and 15 centimetres long, " minipots " of only 15 centimetres' circumference (i.e., 7.5 centimetres laid flat) and only 15 centimetres long are now being extensively used (Allan and Endean, 1966).

In Sudan, experiments on the effect of varying the length of polythene tubes on survival and growth were done with *Eucalyptus microtheca* and *E. camaldulensis* (FAO, 1969b). Ten different lengths were tried varying from 9 to 30 centimetres. The width of the tubes was constant for all treatments. For lengths up to 24 centimetres, survival was 100 percent: this fell to 95 percent for the 27-centimetre tubes and 80 percent for the 30-centimetre tubes. Highly significant positive correlations were obtained between tube length and seedling size and the maximum production of seedlings of 26 centimetres and over in height came from tubes between 15 and 24 centimetres long.

The lower survival in the longest tubes was not explained. As regards growth, it is possible that the smaller size of the plants from the shorter tubes could, to some extent, be compensated for by fertilizer additions either to the soil mixture or to the water applied in post-germination watering.

Polythene pots have a closed bottom and have drainage holes punched in them. Polythene tubes have no bottom. The tubing can be bought in long lengths and cut into the desired lengths and is rather cheaper. A number of countries use pots while others use tubes but there seems to be no consensus of opinion regarding which is preferable. The choice probably depends upon whether the nursery soil available is sufficiently cohesive for tubes and will not fall out of the bottom when they are handled. The cost of medium-sized polythene pots in 1971 was between \$3.00 and \$6.00 per 1 000.

The restriction on lateral root extension by certain types of individual container may cause root distortion, coiling and spiralling. In extreme cases such coiling may lead to mutual strangulation of the roots and the death of the whole

plant. In others it may reduce wind-firmness or lead to stunted growth. Symptoms may not become apparent until four or five years after planting. In the past clay pots have sometimes caused severe casualties or reduction of vigour for this reason.

More recently similar root coiling has been reported in plants raised in polythene pots and tubes. To mitigate the damage, the polythene should be removed from the soil cylinder immediately before planting. In addition, two to three vertical incisions down the length of the soil cylinder, made by a razor blade, sharp knife or hacksaw to a depth of about 1 centimetre, in order to cut any potential "strangler" roots, have been advocated, e.g. in Tunisia (Brahim Ben Salem, 1971; Stone, 1971) and South Africa (Donald, 1968). In Tunisia a further precaution, of slicing off the bottom 0.5 to 1 centimetre of the soil cylinder, has been advised (Brahim Ben Salem, 1971; Stone, 1971). Care must be used to ensure that the soil does not disintegrate and so expose the roots to desiccation.

Confirmatory evidence of similar effects in savanna planting is lacking. In Nigeria experiments investigating the effect of total, partial and nonremoval of polythene pots from plants of pines and eucalypts at planting have shown no significant differences so far (Jackson and Ojo, 1970; Nigeria, Savanna Forestry Research Station, 1971a). Experiments on the removal of planting tubes have in Zambia also shown no significant effect on growth or survival (Greenwood, 1969). Nevertheless, foresters should be on the watch for any signs of root malformation resulting from the use of polythene pots or tubes.

Soil potting mixtures

The need to site nurseries on light fertile soil disappeared with the introduction of polythene pots or other containers, as all the soil used is in the form of imported mixtures. The soil mixture needs to be light but at the same time cohesive. It must be water retentive but should not puddle with watering nor cake when it dries out. It must contain adequate nutrients which are usually supplied in the form of artificial fertilizers. Insecticides are added when protection against termites is necessary and where needed, minor elements (e.g. boron for some eucalypts) can be incorporated in the mixture, or the mycelium of a suitable mycorrhizal fungus

Table 11. — Soil potting mixtures

Place	Soil components	Fertilizer and insecticide additions
	Parts by volume	*Per cubic metre*
East African Agriculture and Forestry Research Organisation, Muguga, Kenya [1]	5 forest topsoil 2 chopped peat 1 clay crumbs 1 crushed stone 1 well-rotted manure	2 kg NPK fertilizer
Nigeria Bukuru	5 river sand 4 composted cow manure	590 g "totafect" fertilizer 118 g dieldrin 2% dust 295 g borate 590 g ammonium sulphate
Naraguta	4 fine sand 1 coarse sand 4 composted cow manure 1 loamy forest soil from plantations of the species to be planted	590 g ammonium sulphate 590 g superphosphate 295 g muriate of potash 590 g dieldrin 2% dust
Ibadan	River sand	1.77 kg each of single granular superphosphate, bone meal, hoof and horn flakes
Zambia [2]	Sandy humic topsoil from the best quality *Brachystegia* woodland within economic reach (top 15-23 cm only)	2.06 kg of NPK compound "M" (N9:P12:K9)
Sudan Kordofan	1 sand 1 clay 1 ground cattle manure	
Tanzania	6 forest or grassland topsoil 1 mycorrhizal soil (for pines) 1 cattle manure 1 sand 1 gravel	2 kg of NPK fertilizer

[1] Although Muguga is outside the savanna region, this was worked out as the ideal mixture. In practice it is commonly simplified according to available local materials.

[2] Fertilizer is omitted if soil is used for seed-beds or for direct sowing in pots and is added afterwards by watering after germination with "Welgro" fertilizer at rates up to 2 tablespoons per 4 litres per running yard of 4-foot-wide bed fortnightly or, in the case of minipots, at less than half this concentration.

in the case of pines. The components of the soil mixtures used vary considerably from country to country. Table 11 gives examples in use in various nurseries.

It will be seen from this table that there is considerable variation in practice between different localities. The various prescriptions have been arrived at largely by trial and error to suit local conditions.

Experiments in Sudan on potting mixtures for the sowing of *Eucalyptus camaldulensis* into pots covered a range of ratios of fine sand/river silt from pure sand to pure silt. The highest percentage germination and survival was in 100 percent sand and the best growth in pure silt. The best compromise with high stocking and good height growth was in the 50/50 percent mixture (FAO, 1969b). Increasing amounts of silt produced a systematic reduction of the root weight/shoot weight ratio and vice versa for increasing amounts of sand.

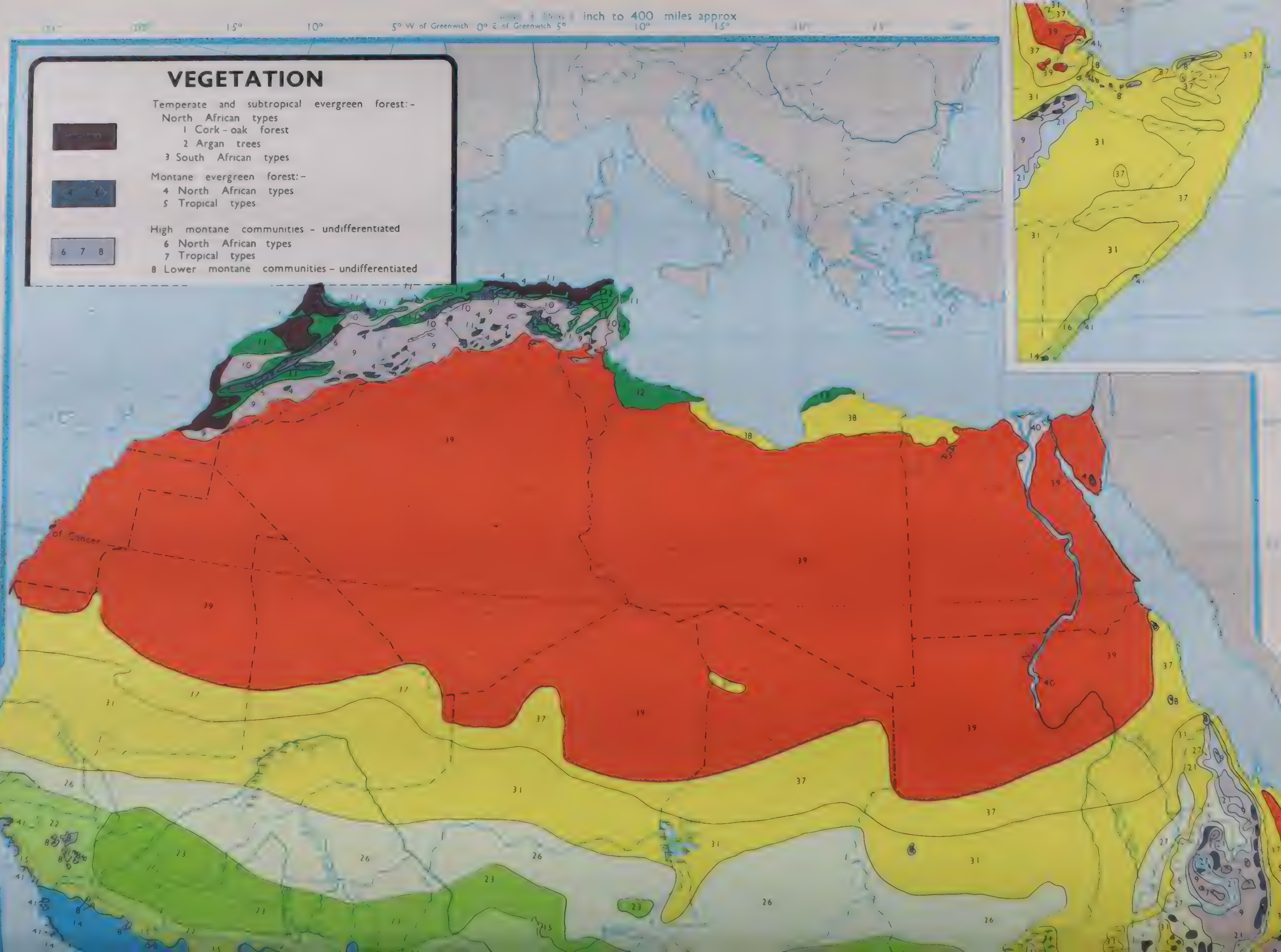
In experiments on potting mixtures at Samaru, Nigeria, it was found that best results for eucalypts were from a mixture of 2 parts of cow dung to 3 of sand, or 3 parts of cow dung to 4 of sand. Cow dung, however, was found to be harmful to *Pinus caribaea* seedlings and the best results were from 1 to 4 or 2 to 3 of forest topsoil to sand with 28 ounces of superphosphate per cubic yard (Jackson, Brandes and Ojo, 1970).

There have been some difficulties with the use of forest topsoil in some east African nurseries. Soil collected at the end of the dry season is found to be deficient in available nitrates (Parry, 1956) and has to be stored for three to four months to allow breakdown of the humus. Sometimes the use of forest topsoil leads to the introduction of weeds, foreign seeds and undesirable microbial activities (e.g. damping off or root disease), and sterilization may be necessary. This is standard practice in Zambia for seed-bed soil or for potting soil in which seeds will be sown directly. Fumigation with methyl bromide is the method usually employed, but it is now considered only as a nursery weed control measure, fungal reinfection being so rapid that sterilization is not an effective fungal control measure. (For details see Appendix 5.)

It is essential that the soil used in savanna nursery work is sufficiently acid. For most species, the pH should not be higher than 6.0, while for pines an upper limit of 5.5 is preferable. On soils more alkaline than this, growth may be poor with symptoms of chlorosis and iron deficiency and seedlings are much more prone to damping off and other fungal diseases. Mycorrhizae of pines do not form readily if the soil is too alkaline. In general, the soils of the more arid savanna tend to be above pH 6.0. If suitably acid soil is not available for nursery work, the more alkaline local soils may have to be used and rendered suitable by acidification. This is practicable if the pH is not higher than 7.0 to 7.5. Acidifying agents are sulphuric acid, sulphur (in the form of flowers of sulphur), aluminium sulphate or ammonium sulphate. Under temperate conditions (Benzian, 1965) it was found that about 190 millilitres of concentrated sulphuric acid in 5.4 litres of water per square metre of nursery bed reduced the pH of the soil by between three quarters and one whole unit. Similar effects were obtained by applying 120 grammes of sulphur per square metre, or doses of aluminium sulphate or ammonium sulphate containing the same amount of sulphur. The effect lasted for about a year but the pH rose in the second and subsequent years. Ammonium sulphate applied as a heavy fertilizer dressing at about 110 grammes per square metre or 1 100 kilogrammes per hectare lowered the pH by a whole unit, and it was possible to maintain the lower pH by comparatively small dressings in subsequent years. The soluble salts produced by any of the above dressings have to be removed, but this should present little difficulty in nurseries where irrigation is available. Whether such treatments will give similar results on savanna nursery soils is not known, but it is worth experimenting to determine the best method of acidifying the soils of savanna nurseries where they are too alkaline. In particular, the use of ammonium sulphate as a cheap and effective acidifying agent merits investigation.

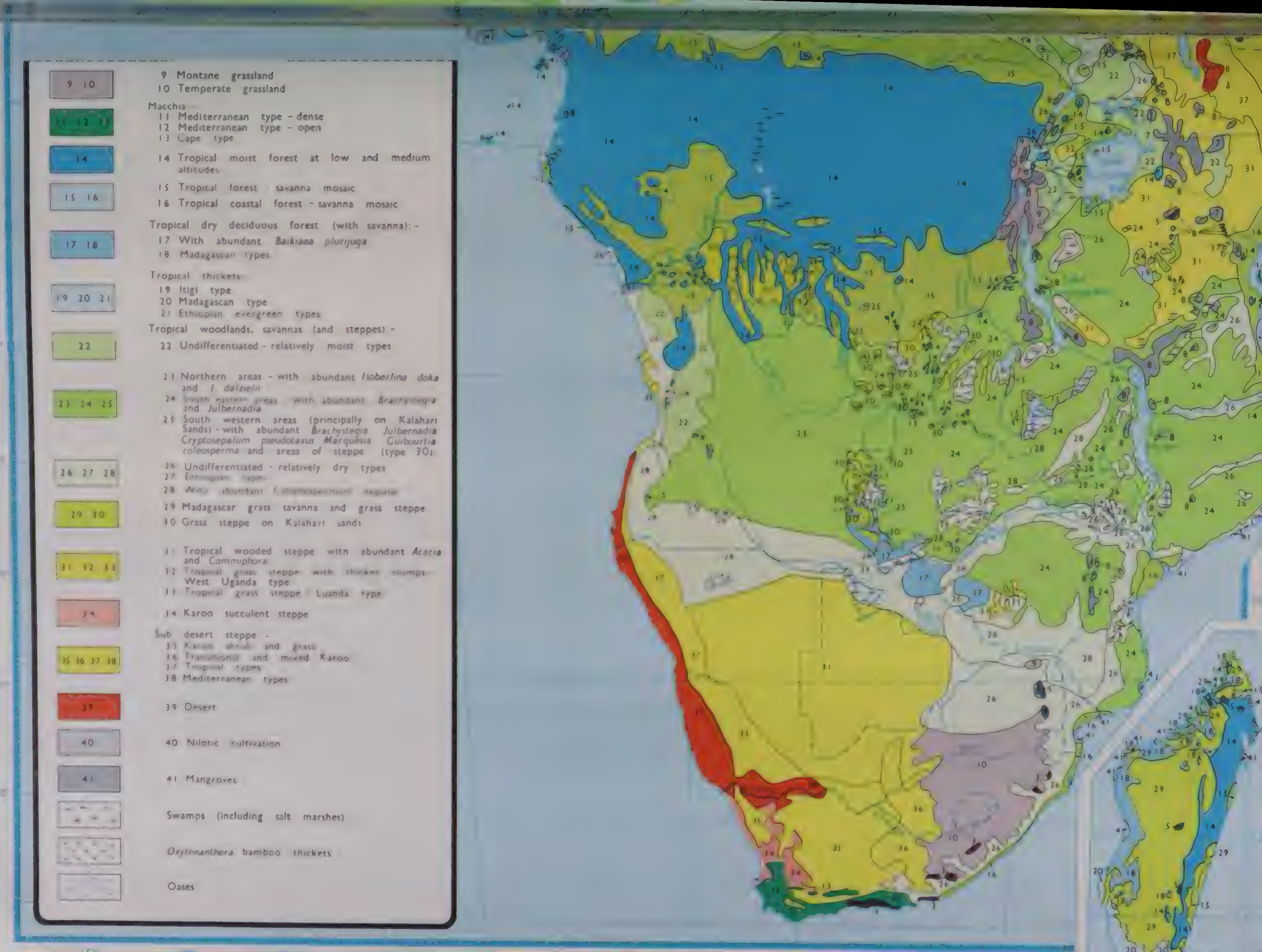
In Zambia, in pine nurseries, when soil that is too alkaline has inadvertently or through force of circumstances been used and the pine plants are small and yellow, acidification is carried out by watering the pots, plants and all, with 13.5 litres of 1 in 1 000 solution of sulphuric acid to every 600 pots. The solution is then washed off the needles to prevent scorching (Allan and Endean, 1966).

The quantity of soil needed in a container nursery is very large. For instance, in Zambia, a programme using 1½ million "minipots" requires about 600 tons of soil annually. Using



inch to 400 miles approx
15°
10°
5° W of Greenwich
0° E of Greenwich
5°
10°
15°
VEGETATION
Temperate and subtropical evergreen forest:-
North African types
1 Cork-oak forest
2 Argan trees
3 South African types
Montane evergreen forest:-
4 North African types
5 Tropical types
High montane communities - undifferentiated
6 North African types
7 Tropical types
8 Lower montane communities - undifferentiated
6 7 8
of Cancer

Map 1



9 Montane grassland
10 Temperate grassland
Macchia -
11 Mediterranean type - dense
12 Mediterranean type - open
13 Cape type
14 Tropical moist forest at low and medium altitudes
15 Tropical forest - savanna mosaic
16 Tropical coastal forest - savanna mosaic
Tropical dry deciduous forest (with savanna): -
17 With abundant Baikiaea plurijuga
18 Madagascan types
Tropical thickets
19 Itigi type
20 Madagascan type
21 Ethiopian evergreen types
Tropical woodlands, savannas (and steppes): -
22 Undifferentiated - relatively moist types
23 Northern areas - with abundant Isoberlinia doka and I. dalzielii
24 and Julbernadia
25 South western areas (principally on Kalahari Sands) - with abundant Brachystegia Julbernadia Cryptosepalum pseudotaxus Marquesia Guibourtia coleosperma and areas of steppe (type 30)
26 Undifferentiated - relatively dry types
29 Madagascar grass savanna and grass steppe
30 Grass steppe on Kalahari sands
31 Tropical wooded steppe with abundant Acacia and Commiphora
32 West Uganda type
34 Karoo succulent steppe
Sub desert steppe -
36 Transitional and mixed Karoo
38 Mediterranean types
39 Desert
40 Nilotic cultivation
41 Mangroves
Swamps (including salt marshes)
Oxytenanthera bamboo thickets
Oases

Map 1


SOILS
1 Desert, undifferentiated.
2 Desert, sands, dunes (ergs).
3 Desert, pebble-strewn surfaces (regs)
4 Desert, calcareous crusts (gypsum)
5 Bare rock and rock debris.
6 Skeletal soils, mostly rock debris with pockets of soil.
7 Weakly developed soils on young alluvium, often halomorphic or hydromorphic.
8 Soils developed on recent volcanics.
5° W of Greenwich
0° E of Greenwich
5°

Map 2

15° 10° 5° West of Greenwich 0° East of Greenwich 5°

Zenithal Equal-area Projection Origin 15°N & 20°E

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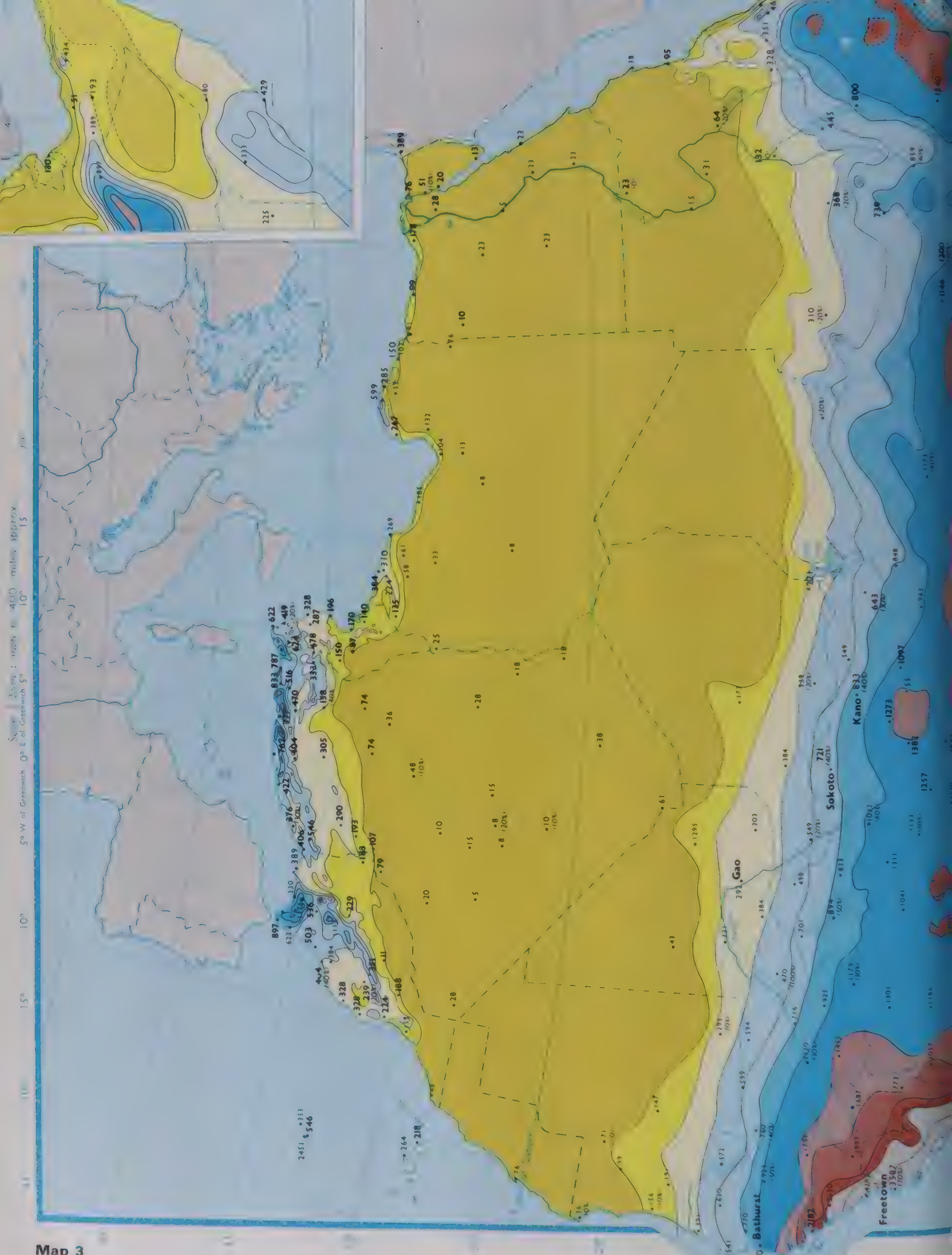
Map 2



Map 3

Mean Annual RAINFALL
including all forms of precipitation
200 600 1.000 1.800 2.600 4.000
100 400 800 1.400 2.200 3.200
Figures show mean annual values in millimetres at climatic stations
Style of figures indicates number of years on which mean annual values are based
15-19 years
20-24 years
over 25 years
Probability that the rainfall any year will be the
the mean annual rainfall
Tropic of Capricorn
Luanda
Kasama
Entebbe
Zanzibar
Salisbury
Beira
Maun
Bulawayo
Windhoek
Johannesburg
Keetmanshoop
Kimberley
Durban
Cape Town
Tananarive

Map 3

standard pots of 25-centimetre circumference (12.5 centimetres folded flat and 15 centimetres deep) the amount of soil required per 1 000 pots is about one ton, which suggests that soil collection and handling should be mechanized for any nursery supplying plants for a large planting programme.

Sowing seed

Hitherto the usual method of raising plants has been to sow the seed in seed-beds or boxes and to prick out into pots as soon as the plants are sufficiently large to handle, which is usually one to three weeks after germination. This is a delicate and time-consuming operation and care must be taken not to damage the seedlings which should be held by a leaf and never by the stem. Recently, however, the tendency has been to sow direct into the polythene pots which has the advantage of saving the labour and the losses incurred in pricking out as well as avoiding the check in growth caused by transplanting. This has been established practice in Sudan for several years for eucalypts and a number of other species, and has proved very successful so long as ample seed is available. In Zambia, also, direct sowing into "minipots" is becoming standard practice and Nigeria and most other countries are following suit, as it is found to cut down time and costs in the nursery considerably. Precautions may have to be taken to ensure that the amount of fertilizer used in the soil mixture is not so great as to inhibit germination, and, as already indicated, this problem is avoided in Zambia by omitting the fertilizer additions to the soil mixture and supplying the necessary nutrients after germination by watering with a fertilizer solution at fortnightly intervals. An alternative is to add 1 to 2 centimetres of pure sand as a surface layer in the pots, to form the germinating medium.

Regarding the amount of seed sown per pot, the following figures from Nigeria are illustrative.

Quantity per 100 pots	*Species*
0.5 grammes of seed	*Eucalyptus deglupta*
1.0 grammes	All other *Eucalyptus* spp. in the list on p. 78-79 except those mentioned below
1.66 grammes	*Chlorophora* spp.
2.0 grammes	*Eucalyptus pilularis* and *E. punctata*
3.0 grammes	*E. tereticornis* — Zambia provenance. (New Guinea provenance is sown at 1.0 grammes per 100 pots)
2 to 3 seeds per pot	*Eucalyptus citriodora, Pinus* spp.

In Zambia, three to seven seeds of *Eucalyptus "grandis"* are sown per pot from a "shaker." In Nigeria, Fishwick, 1966, describes a method of sowing small numbers of seeds too minute to count, using a needle dipped in starch solution.

Other methods of raising whole plants

Balls of earth and soil blocks

Prior to the now almost universal use of polythene pots or tubes, soil balls and soil blocks were widely and successfully used. As practised in Mauritius, the plants are raised in seed-beds in the usual way and at the transplant stage are then enclosed in balls of earth. The soil for this purpose is mixed to a suitable consistency and formed into two rough hemispheres with a depression in the flat face of one for the roots of the transplant. The transplant is placed in this and the two hemispheres pressed together to form a ball in which the transplant remains until it is planted out.

The soil block technique is somewhat similar, blocks of potting soil, usually hexagonal in section, being compressed in a machine. There is a small depression in the top, filled with sand, in which the seed is sown. This method is used extensively in Brazil and also in Sudan (Kordofan) for raising *Acacia senegal* seedlings.

In both the ball of earth and the soil block methods the soil mixture is critical, as, if the right mixture is not obtained, the balls or blocks will disintegrate and will not last until planting nor stand up to jarring during transport. They are thus not applicable everywhere and the making of the soil mixture requires close supervision to ensure consistency of quality. But given the right conditions, these methods can be effective and cheap. For further details of these and of other container techniques, Goor and Barney, 1968, may be consulted.

Boxes

In the relatively harsh conditions of the savanna, individual containers provide the best insurance against drying out of roots, which is easily the most common cause of planting deaths. Plants raised in boxes and undercut beds, a method which has been common practice in the cooler conditions of the east African highlands, are not suitable for use over most of the savanna. A brief description is given here, for comparison with container techniques, and because these methods may have a limited use in very favourable areas in the derived savanna zone.

A typical open-topped wooden planting box is about 38 centimetres square and 12 centimetres deep. The bottom should be slatted, with a 1-centimetre gap between slats, to allow free drainage. If other material is used, e.g. metal or plastic, an adequate number of drainage holes must be punched in the bottom. Young seedlings are transplanted into the boxes at a 5×5 centimetre spacing, giving 49 plants per box (Parry, 1956). Fortnightly intercutting between the rows is done with a sharp knife, each week in alternate directions, in addition to periodic lifting or undercutting to prevent rooting through the bottom slats. This ensures the development of a dense mass of fibrous roots, with the root system of each plant in its own cube of soil, and there is no possibility of spiral roots developing. At planting time, the boxes are taken to the planting site, and each individual plant is removed and planted, complete with cube of soil. If the work is efficiently organized to ensure the minimum interval between a plant leaving the box and being planted, the method can give excellent results. But if the soil cube is left exposed to hot sunshine for a period or falls off as a result of careless handling, heavy casualties can result.

Undercut beds

This method originated several decades ago in Swaziland, whence the beds are sometimes known as Swaziland beds. In the method described by Parry, 1956, the seedlings are transplanted into a long bed about 1 metre wide, built up of an imported soil mixture. The bed is enclosed by bricks, cement blocks or wooden baulks 12 centimetres deep, and rests on a flat surface of compacted soil. Spacing is the same as in boxes. The bed is undercut once a week by drawing a length of piano wire (gauge 16, 18, 20 or 22) along beneath it. During this operation the bricks or baulks remain in place and serve to hold the wire down to the right level. The wire is operated by two men pulling alternately as though they were using a flexible saw. The cutting should be done in alternate directions each week to prevent long roots being dragged horizontally without being cut cleanly. Intercutting between rows is done in the same way as for boxes.

At the time of planting the side baulks are rolled away and the bed carved up into sections of the right size to fit into a box.

Plants are transported to the field in boxes which may be used several times over. One side of each transport box may be left open so that the section can be slid into the box with a minimum of disturbance. The double process of lifting in the nursery and removal from the boxes at the planting site usually leads to more damage to the soil cubes than in the box method.

Where planting conditions are exceptionally favourable, plants may be lifted, the soil shaken off, the roots puddled in a mud slurry and the entire plants packed in bundles of 50 in a large polythene bag within moist sacking. In this condition they may be transported to the field and planted bare-rooted. This method avoids the transport of large weights of soil and allows the nursery beds to be used several years in succession, with simply a topping up operation to replenish the full depth of soil in the beds. As a general rule, bare-root planting is too risky to be considered a practical proposition in any but the best conditions, but the development of new and more effective materials for root dipping such as sodium alginate, could make it more attractive. Whenever it can be counted on to produce reliable results, the effective saving in cost becomes considerable, since transport of soil to and from the nursery is one of the most expensive items in the plant-raising process.

Stump raising

Species suitable for planting as stumps are: *Azadirachta indica*, *Cassia siamea*, *Conocarpus lancifolius*, *Chlorophora excelsa* and *C. regia*, *Dalbergia sissoo*, *Gmelina arborea* and *Tectona grandis*. Stumps are root and shoot cuttings and a rough rule for size for most species is

" thicker than a pencil but thinner than a thumb " and in length about 25 centimetres, of which about 22.5 centimetres should be below the root collar. For *Chlorophora* rather larger stumps of at least 2.5-centimetre diameter are generally used. In all species, the diameter has a much greater effect on survival and growth than the length, and minimum diameters below which casualties increase rapidly are critical. The time taken in the nursery bed to produce stumps of adequate size varies with species but is longer than for plants raised in polythene pots or other containers. The enormous advantages of stumps are their ease and cheapness of transportation and their toughness. While it is obviously desirable to plant them out as soon as possible after they have been prepared, stumps of some species may retain their viability for up to a fortnight or more if stored in shady conditions.

The new root development of stumps after planting in the forest takes place from the cambium at or near the tip, and it usually starts before development of any buds above ground. The best conditions for planting stumps are therefore when the soil at the depth of the tip of the stump is not bone dry (though the surface soil may be), and about a week to 20 days before the main rains, when above-ground bud development usually starts. If conditions are just right, this prerains planting results in much greater first season growth than planting after the main rains start, and without any increase in casualties. The best date of planting of stumps of any species in any particular locality has, however, to be determined by simple date-of-planting experiments repeated over a number of years.

Open-rooted bed nurseries, as distinct from container, box or root-pruned bed nurseries, are used in savanna planting almost exclusively for the production of stumps. Such nurseries must be situated on suitable soils (i.e. light sandy soils which are well drained), and at the same time must have an adequate water supply. "Flying nurseries," i.e. temporary nurseries situated near the plantation area which rely for water on rainfall and which are only used for a year or two, are giving way to large permanent irrigated nurseries in all extensive plantation projects. The advantages are the possibilities of building up a well-trained and experienced nursery staff under skilled supervision, of mechanizing certain operations and in general of exercising closer control over quality. These usually outweigh the disadvantages inherent in permanent nurseries, such as the problems of soil fertility maintenance over long periods of time, the build-up of salts, lime, etc. from years of irrigation, and of root disease organisms in the soil necessitating partial sterilization from time to time.

In raising plants for stumping, either

(*a*) seed may be sown broadcast or in drills directly in the beds where they will remain until ready for stumping; or

(*b*) seed is sown in special seed-beds and pricked out into the final nursery beds when large enough to handle; or

(*c*) it may be pregerminated in moist sand or vermiculite from which the germinating seed is sifted out at frequent intervals and sown in the final beds at a suitable spacing.

Where regular, even germination is obtained method (*a*) is usually to be preferred but the plants may have to be thinned out to a suitable spacing in order to obtain plants of a stumpable size in one growing season. Where germination is irregular or takes place over a long period, methods (*b*) or (*c*) are normally adopted so as to ensure fully stocked uniform beds for stumping. Wherever appropriate, seed should have been pretreated before sowing (see p. 77).

Plants for stumping usually remain in the nursery beds for ten months to a year, but the time depends upon how long any particular species takes to attain adequate size for stumping. Sowing dates may need to be adjusted accordingly. When the plants are lifted for stumping, the normal practice is to clear the beds completely, throwing away any undersized plants. In some cases, however, if plant size is very variable, e.g. in beds sown directly by method (*a*) above, the beds are thoroughly watered, loosened with a fork and only the large plants of stumpable size pulled out. The bed is then reconsolidated and watered, the remaining undersized plants together with ungerminated seed producing a well-stocked bed of stumpable plants at the end of the second season (this method is especially applicable to teak). In general, however, methods (*b*) or (*c*) are preferred in which nearly all the plants should reach stumpable size at the end of the first season.

Cultural and protective practices

Shading

In arid areas the seeds of most species germinate more readily under light shade than in full sunlight because it is easier to maintain suitable moisture conditions for germination under such shade. Newly germinated seedlings, moreover, have soft succulent stems that are particularly susceptible to heat damage even though adequate soil moisture is available. Seed-beds and freshly sown pots or other containers are, therefore, usually shaded all through the germination period and for a short time after, until the seedlings are large enough to stand gradual exposure. However, where climatic conditions are not too severe, satisfactory results may be obtained with no shade. For example, at Samaru, Nigeria, shading has been found unnecessary for most species, other than pines, when sown direct in pots.

Seed-beds or beds of sown pots may be shaded by covering them with sacking or white cotton material mounted on light frames for ease of handling. These frames should be supported over the beds on strong, taut wires fixed on short posts. A convenient height is about 30 to 40 centimetres. Alternative methods are rollable screens of wooden slats or split bamboos giving about 50 percent shade. The sides of the beds should be left open for ventilation. Fabric shades such as burlap, etc. can be treated with copper napthanate as a preservative and, if so treated, may last up to four times as long as untreated material. The shades have to be removed when watering and also in rainy weather as the drip from them may be damaging. When germination is completed the amount of shading should be reduced and finally removed as quickly as the seedlings in question will tolerate it.

In experiments to test the effect of shade on the development of *E. camaldulensis* seedlings in Sudan the best results, giving the maximum number of seedlings combined with the greatest and most uniform height growth, were obtained with initial shade until the seedlings were 10 centimetres high after which all shade was removed. The growth period was 158 days and the height of the seedlings 41.3 centimetres as compared with 26.6 centimetres for seedlings grown with no shade at all (FAO, 1969b).

Transplanting seedlings is a critical operation in the life of nursery stock and special precautions must be taken to avoid damage from heat and excessive insolation, especially when transplanting takes place in the hot, dry season. Once established, however, the plants will not suffer damage from high temperatures provided such temperatures are not associated with drought. Shading of transplant beds is, therefore, a temporary operation and any shades used should be removed entirely within one to three weeks after transplanting. In some countries, permanent lath houses are used, but these have the great disadvantage that the pots have to be brought into them for transplanting and then have to be removed outside again after one or two weeks into full sunlight. Gradual reduction of shade would entail great labour in moving pots in and out of the houses. In large permanent nurseries it may be worthwhile to have special portable devices which protect the stock from heat during and after transplanting but which can be easily removed when the shade is no longer required. A useful arrangement consists of light, transportable, wooden frames covered with canvas or cloth material held 30 to 50 centimetres above ground on short stilts. Several of these placed end to end can shade an entire bed. Four to six days after transplanting, the frames can be moved to other beds where transplanting is still in progress (Goor and Barney, 1968).

Sheltering

Where hot, dry winds occur, there may be damage to young seedlings and reduction in growth of plants of all sizes in the nursery, even under shade. In such cases it may be desirable to divide the nursery up into sections by means of screens positioned at right angles to the prevailing winds. These may be of coarse cloth, sacking or other materials fixed to poles, or live hedges may be used. A good shelterbelt of trees on the windward edge of the nursery is also of great benefit. In a well-sheltered nursery, not only is damage from desiccation reduced, but light sandy seed-bed covers can be used without danger of the cover together with the seeds being blown away. Growth rates are improved and the time taken to reach plantable size in the nursery is reduced.

Protection by a waterproof material is sometimes needed for young seedlings against heavy rain, but this can often be avoided if the seed is sown early enough so that plants are well established by the time the first rainstorms begin.

Watering

Water is commonly one of the limiting factors in locating nurseries for savanna planting. The supplies needed are considerable, e.g. over 30 litres per 1 000 plants per day for eucalypts in Zambia. The water must be of good quality and nonsaline, and before siting a large nursery it is advisable to have the water analysed, particularly if watering by irrigation is contemplated. If the water contains more than about 550 ppm (parts per million) of dissolved solids, it is highly undesirable for irrigating permanent bed nurseries as it will raise the pH of the nursery bed soil which, in turn, will favour an increase in damping off and root rots, inhibit iron metabolism and cause chlorosis. If such water must be used, acidification or other expensive soil treatment will be required to reduce the pH to an acceptable level. Lime, in particular, in the water cannot be tolerated in quantities over about 100 ppm. The species raised and the cultural practices also affect the amount of dissolved solids that can be tolerated. Conifers, in general, are more susceptible to lime than most broad-leaved species. Potted plants which remain in the nursery for a relatively short time will tolerate higher proportions of dissolved solids in the water than plants raised in permanent beds, where accumulation of salts can rapidly build up to toxic amounts in a layer a few centimetres below the surface.

FIGURE 23. Hand watering *Pinus kesiya* seedlings in large polythene pots at Ndola, Zambia.

(*Courtesy* Forest Department, Zambia)

Watering may be either by hand or by irrigation. In nearly all large permanent nurseries, irrigation in one form or another is the generally adopted method. Not only is it more economical but it is more efficient, as the distribution can be more uniform and the quantities of water applied more accurately controlled. It is very difficult to obtain uniform and consistent watering by hand, the middle of the bed almost always receiving more water than the sides.

Irrigation may be the traditional trench irrigation, or more usually overhead spray irrigation, and the latter is of two main kinds, namely oscillating sprays or rotating sprays. Perforated static lines may also be used.

FIGURE 24. *Azadirachta indica* in beds and polythene pots with nozzle-line sprinkler irrigation system at Sokoto, Nigeria.

(*Courtesy* J.K. Jackson)

For watering seed-beds or pots in which seed has been sown, a very fine droplet size is essential, otherwise the seeds may get washed out of the ground, the seed covering material washed away and the soil surface consolidated or "capped." Hand watering of seed-beds is commonly done with a fine-rose gardener's watering can or a knapsack pressure sprayer fitted with a fine mist-producing nozzle. For irrigation, only oscillating sprays with fine nozzles should be used for seed-beds. The droplet size in rotary sprayers is too large.

Transplant beds and beds of pots containing established plants can be watered by rotary sprayers. In these the droplet size is much larger. The drops carry further and a bigger

area can be covered by each spray. Watering is quicker. It has the disadvantage of covering circular areas so that the sprays must overlap to get complete coverage and the distribution is uneven. Rectangular areas are covered by oscillating sprays and by static lines and these are usually to be preferred. In all cases care has to be taken that the droplet size is kept sufficiently small so as to avoid consolidating the surface. In pot nurseries, the pots must have adequate drainage holes so as to avoid waterlogging.

The quantity of water necessary depends upon the weather, and the texture of the soil used. In seed-beds the aim should be to keep the soil moist (not saturated) down to a depth of about 15 centimetres, but overwatering must be avoided, otherwise conditions favourable to damping off will be created. Once a week, the beds are watered with a solution of Zineb (a zinc-based fungicide) to prevent damping off (Zambia). In transplant beds and pots with established seedlings, the quantities of water needed are greater. Zambian practice suggests an average of 5 to 6.5 millimetres per day for pines and 7.5 to 9.5 millimetres per day for eucalypts. This is equivalent to 24 to 30 litres per 1 000 plants per day for pines and approximately 32 litres per 1 000 plants for eucalypts. These are figures of maximum use. When the plants are small they will use less water and the quantities will vary with the weather. For minipots, the quantities are the same *per unit area*. These figures from Zambia are given by way of illustration. In most places the amounts of water applied are arrived at by trial and error.

As the planting season approaches, a gradual reduction of watering intensity, relative to plant demand, is a common means of producing " hardened off " stock — sturdy, well-balanced, semiwoody plants ready for field planting. Other possible means of producing hardened off stock may be through adjustment of the fertilizer balance by reducing nitrogen applications combined with addition of potassium (FAO, 1970c).

Regarding the frequency of watering, this can vary greatly. Seed-beds in arid areas may require light watering as often as four times a day, while for older plants growing under less severe conditions once in two days may be sufficient.

Specifications of irrigation equipment used in Nigerian nurseries are given by Fishwick, 1966, and a general treatment of the principles of nursery irrigation is given in Appendix 6.

Root pruning

The roots of plants in polythene pots or tubes soon emerge from the bottom and will grow down into the soil of the bed beneath if not cut. The purpose of root pruning is not only to prevent the development of a long tap root but also to encourage the growth of a fibrous lateral root system in the pot or bed. The pruning can be done by drawing a taut piano wire between the base of the pots and the bed surface so as to cut through any descending roots. Alternatively it can be done by lifting the pots and thus snapping off the roots, called wrenching. To facilitate wrenching a space about 30 centimetres (1 foot) wide should be left at the end of each block of pots so that successive rows of pots can be moved along as they are lifted. In Zambia, pines are normally root pruned by wrenching when about five to six months old and again about two weeks before planting. For eucalypts, the roots of which proliferate much more rapidly, root pruning has to be done weekly once the roots have come through the bottoms of the pots. The plants may tend to wilt after pruning and they should be watered thoroughly and, if necessary, shaded for a couple of days after pruning. The last pruning should take place not more than a week before planting.

Other species will need similar attention, the timing and frequency of the pruning being adjusted according to the speed with which the roots develop and emerge from the bottom of the pots. In general, cutting them with a piano wire is considered preferable to breaking them by lifting the pots.

An alternative method, hitherto little used in African savanna nurseries, is to stand containers on an angle-iron frame with a wire netting of 1-centimetre mesh, fixed on concrete blocks. Two thicknesses of newspaper are placed between the wire and the containers. Since the frame is about 30 centimetres above ground level, the development of roots is stopped as soon as they penetrate the newspaper, and the need for manual root pruning is eliminated. This method has given successful results in Costa Rica, using as pots metal sleeves 12 centimetres long and 6 × 6 centimetres in cross-section which mav be reused repeatedly.

Size of plants and grading

There seems to be little agreement on the best size of plants for planting out. In Sudan, the normal size of eucalypt plants for planting in irrigated plantations is about 25 to 30 centimetres; and 25-centimetre-tall plants are commonly used in Nigeria. In Zambia, however, there is a definite tendency toward using smaller plants. Accepted sizes, which were until recently 12.5 to 20 centimetres for eucalypts, are now 10 to 15 centimetres, anything over 15 centimetres being regarded as unsuitable. Such plants take about 2½ to 3½ months to produce in minipots from date of sowing. Once a *Eucalyptus* plant has reached about 15 centimetres in height it starts growing very rapidly, at a rate of 0.8 to 1.2 centimetres a day, and may quickly become too big. With such rapidly growing species, sowing dates have to be judged very accurately if stock of the best size is to be produced by a specified planting date. In the case of pines raised in standard size pots, 15 to 20 centimetres tall is the specified size in Zambia and emphasis is laid on 20 centimetres being the absolute maximum. If produced in minipots, 12.5- to 15-centimetre-tall plants are regarded as standard, anything taller being considered undesirable. Such pine plants take seven to eight months to produce (Allan and Endean, 1966).

Stock should be graded when about two thirds of the nursery period has passed. Zambian practice is to grade into four classes at the time of wrenching: "large," "average," "small," and "culls." Culls will include excessively stunted, abnormal or forked plants, and are usually thrown away. The three remaining classes are placed in separate beds and are treated to achieve as much uniformity as possible, e.g. the watering of the large plants is reduced in quantity and the small plants receive extra care to stimulate their growth. More recently, however, the use of monthly spaced sowings together with an improved watering system and the application of liquid fertilizer is expected to result in the elimination of the grading system as such, leaving culling only. The undesirable habit of later planting with slower growing or checked stock will also be prevented.

Protection in nurseries

Apart from drought, desiccation and heat damage which have already been mentioned, the main troubles against which protection may be necessary are damping off and other fungal diseases and insect damage, particularly from termites.

In nurseries where fresh soil mixtures are prepared annually, the need for soil fumigation does not usually arise, though occasionally damage to seedlings by root fungi, damping off or insect attack may indicate the desirability of fumigation. It is more often likely to be necessary in beds that are repeatedly cropped using the same soil. Seed-beds, in particular, are usually fumigated, whether of fresh soil or old soil. In Zambia fumigation with methyl bromide is standard practice. Details of the procedure are given in Appendix 5. Other fumigants are sometimes used, e.g. "Nemagon 20" and "Dowfume M.C.2" in Nigeria. Applied to seedlings at least 26 days before transplanting into pots, they had no bad effects and are claimed to reduce post-transplanting damping off (Jackson and Ojo, 1970).

"Damping off" is the most serious trouble experienced in savanna nursery work. It can occur both in nursery beds and in polythene pots after pricking out. It is especially prevalent in pine seedlings, though many other species suffer from it. A number of different fungi can be responsible. Although soil treatment with formalin or fumigation with methyl bromide or other fumigants can give significant improvement in the numbers of seedlings that emerge, such treatments are not consistently effective. A possible reason for this is rapid recolonization of treated beds, the pathogens being introduced from surrounding soil on dirty tools or possibly on the seed itself.

Experiments in pelleting the seed with a number of fungicides in large doses ("vapam," "captan" and others) have given inconsistent results under African conditions, possibly due to the wide spectrum of fungi responsible (Hocking and Jaffar, 1969). In these experiments, the only treatment that gave a high degree of control combined with negligible phytotoxicity was "Rhizoctol" at a high dosage of 1 to 3 percent of the seed weight in a sticker of 4 percent hydroxypropyl methyl cellulose (at 25 percent of the seed weight). ("Rhizoctol" is a Bayer product containing 10 percent methylarsinic sulphide.) This pelleting treatment should be combined with bed fumigation and good cultural practice, using clean tools and hands when pricking out.

While termites are not usually troublesome in the nursery, they can cause wholesale destruction to young plants of certain species, notably many eucalypts, when planted out in the field. It is customary to include an insecticide in the soil mixture in the nursery to provide post-planting protection. The insecticides commonly used are either dieldrin or aldrin and they may either be mixed with the soil (e.g. 0.8 kilogrammes of 2 percent dieldrin powder per cubic metre of soil); or they can be mixed with water as a suspension and watered on. In Zambia 200 to 400 grammes of aldrin wettable powder in 24 litres of water is applied to 1 000 plants in standard pots three times, namely one, two and three weeks after pricking out, so that the insecticide can accumulate in the soil before the foliage is large enough to deflect the watering.

Both dieldrin and aldrin are persistent organochloride insecticides which permanently pollute the ecosystem and their use has been banned in many countries for agricultural purposes. In savanna planting in Africa the quantities used are small in relation to the areas concerned and no immediate effects are likely to be observed. In view, however, of the permanent and cumulative effect of such chemicals, research is urgently required to find some alternative substances that are effective but at the same time are utimately broken down into harmless compounds in the soil.

Protection against grasshoppers and other leaf-eating insects can be achieved by spraying the plants with a suspension of dieldrin or aldrin wettable powders together with a " sticker." A cheap and effective sticker is " sugar-soap," 21 grammes in 1 litre of water, but there are many others just as good. (Sugar-soap is a white, powdery substance, somewhat caustic and strongly detergent, which when dissolved in water is used for cleaning paintwork and other greasy surfaces, and in stronger solutions as a paint stripper. It is inexpensive and is obtained from ironmongers and paint shops.) Cutworms and white grubs which work below the soil surface can be controlled with such a spray (without the sticker) or by the application of chlordane at the rate of 9 kilogrammes per hectare mixed by cultivation into the top 20 centimetres of the soil when preparing the beds.

Birds and rodents are sometimes troublesome, especially in seed-beds. The best protection is surrounding and covering the beds with fine-mesh (not more than 6 millimetres) wire netting. Some protection can be obtained by the use of repellants such as anthroquinone products (Arasan, Morkit), or tetramethylthiuram disulphide (" thiuram ").

12. ESTABLISHMENT OF CLOSE PLANTATIONS

Planting

Planting falls into two categories, close planting and enrichment planting, which is normally at wide spacing. This chapter relates to close planting, which is by far the more important. Enrichment planting is considered in Chapter 13.

Pure planting is almost invariably the practice in the savanna region. Mixtures are not favoured because of the different rates of growth and tending requirements of the component species which usually make subsequent management too complicated and difficult.

Spacing and pegging out

After the site has been cleared and prepared as described in Chapter 9 (the last harrowing of which should be done as near to the planting date as possible, so as to avoid regrowth of weeds and to present clean ground for planting), the area has to be pegged out at the desired espacement. Where hand weeding is to be done, accuracy of spacing in the lines is not very important but where, as in most large plantation projects, mechanical methods of weeding and cultivation are to be employed, it is essential that the pegging out be done accurately in a square pattern so as to provide clear runs for the machinery in both directions at right angles.

The spacing between plants varies with the species used, the purposes for which it is grown, the availability of soil moisture at critical periods of the year and the tolerance of the species to weed competition. These requirements may be conflicting; e.g. a close spacing, giving early closure of canopy may be desirable to suppress weeds and particularly grass, while on the same site, soil moisture may be limiting at certain times of the year and demand a wider spacing if stagnation of the plantation due to shortage of moisture is to be avoided. In such a case, the wider spacing should be adopted and the extra cost of weeding for a longer period accepted until the canopy ultimately closes.

Hitherto, spacings have in most cases been arrived at arbitrarily without a full knowledge of the effects. Preliminary data from recent experiments give some indications of the magnitude of these effects. For instance, at Maigazari in the Sudan zone of Nigeria, experiments in plantations of *Azadirachta indica* have shown that the initial height growth and the individual stem diameters are markedly reduced at closer spacings as the following figures for two-year-old plants demonstrate (Nigeria, Savanna Forestry Research Station, 1968).

Spacing	Height
Metres	
0.9 × 0.9	2.0
1.8 × 1.8	2.6
2.7 × 2.7	2.8
3.7 × 3.7	3.4
5.5 × 5.5	3.8

It is known from experience that at the closer spacings the trees would not survive for more than a few years without thinning.

Again, experiments with eucalypts on the Jos Plateau of Nigeria showed increases in individual stem diameter for the wider spacings, but this was accompanied by a decrease in basal area and hence in volume per unit area (Nigeria, Savanna Forestry Research Station, 1968). The following figures were for five-year-old crops:

TABLE 12. — EFFECT OF SPACING ON GIRTH AND BASAL AREA

Spacing	*E. camaldulensis*		*E. rudis*	
	Girth	Basal area	Girth	Basal area
Metres	*Centimetres*	*Square metres/hectare*	*Centimetres*	*Square metres/hectare*
1.37 × 1.37	15.7	10.3	14.0	8.5
1.83 × 1.83	18.3	9.0	15.5	5.8
1.83 × 2.74	21.0	7.1	16.6	4.4
2.74 × 2.74	21.8	5.3	19.5	4.4

Though indicating a considerable reduction in overall production for the wider spacings at five years old, these figures give little or no indication of the effect of initial spacing on production at the later stages of the rotation, when factors such as intertree competition for available soil moisture may become much greater, unless they have been relieved by timely thinning. For fuel production or small poles initial spacing can obviously be closer than for large poles or timber production, though in the latter case, thinnings will almost certainly be made. Nevertheless, even with heavy thinning regimes, the effects of initial espacement persist right through to rotation age and the shorter the rotation the greater they will be. Much more research is required over the whole rotation to determine the best espacement/thinning regime for any species grown in any locality for any particular purpose.

Some typical spacings at present in use are given in Table 13 as examples.

TIMING OF PLANTING

The usual practice is to start planting as soon as a certain quantity of rain has fallen or the soil is wet to a specified depth. This has to be judged on the basis of local knowledge and the commonest error is to start planting too soon. In Zambia, for instance, planting is started when the soil is moist to a depth of about 30 centimetres, the essential point being to wait until there is sufficient available moisture in the soil to keep the plants alive and growing until the next probable rain.

Such methods depend upon the judgement of individuals and, while reasonably satisfactory with experienced foresters, they can lead to considerable errors with inexperienced ones. It is almost as serious to start planting too late as too soon. If planting is started too soon, heavy casualties from drought before the rains set in may be incurred, but this is a gamble that may sometimes be worth taking in the knowledge that partial replanting of the first planted areas

TABLE 13. — SPACINGS USED IN SAVANNA PLANTATIONS

Country	Species	Spacing		Remarks
		Feet	*Metres*	
Zambia	*Pinus kesiya*	9 × 9	2.77 × 2.77	Grown for timber or large poles. Thinned and pruned three times in a 30-year rotation. Weeding by machines.
Zambia	*Eucalyptus "grandis"*	12 × 12	3.65 × 3.65	Grown for timber and large poles. Pruned once and thinned twice in 8-year rotation. Weeded by machines.
Nigeria	*Eucalyptus* spp.	6 × 6 to 8 × 8	1.8 × 1.8 to 2.4 × 2.4	Fuel and small poles in the Sudan zone. Hand weeding.
Nigeria	*Eucalyptus* spp. and *Pinus* spp.	9 × 9 or wider	2.7 × 2.7 or wider	Where mechanical weeding is done.
Nigeria	*Gmelina*	8 × 8	2.4 × 2.4	For poles and pit props. Hand-weeded.
Nigeria	*Gmelina*	9 × 9	2.7 × 2.7	For larger poles and timber.
Nigeria	Teak	9 × 7	2.7 × 2.1	—
Sudan	*Acacia senegal*	13 × 13	4 × 4	Gum production. May be too close.

may be possible. If it is started too late, not only may it be difficult to complete a large planting programme in time, but the plants will lose the maximum benefit of the rains after planting, which may be a serious matter in savanna conditions where the rainfall is low and erratic.

What is badly needed for savanna conditions is a formula or formulae to determine the soil moisture build-up based on daily rainfall and temperature readings, on the lines devised at the East African Agriculture and Forestry Research Organisation for the highland sites of east Africa (Griffith, 1957). Briefly this consists of ascertaining the daily loss of moisture from the soil by evaporation (by a formula based on actual measurements) and the daily gain from rainfall. A running gain and loss account is kept, until a certain amount of soil moisture has accumulated, when planting is commenced. This amount has to be determined for each planting locality and depends on the rate at which the soil loses moisture, the local probability of rainfall occurrence and the species being planted with regard to its rate of root production and the length of time it can survive without rain on a certain build-up of soil moisture. Such a procedure brings greater certainty into the decision of when to start planting, but even with such information, some judgement may be necessary based on a knowledge of local patterns of rainfall.

Transport of plants

Plants in polythene pots or tubes are usually packed into open-topped boxes for transport to the planting site. A common size is 38 × 38 × 13 centimetres which takes about 16 pots of 25-centimetre circumference or 50 "minipots" of 15-centimetre circumference. The plants should be thoroughly soaked before leaving the nursery. Where possible transport should be by double-deck trailers drawn by tractors, as by this means the plants can be taken right into the planting area and double handling is avoided. The slower speed of a tractor as compared with a lorry avoids both jolting and wind scorch which may occur in faster lorry transport. The rate of supply of plants should be so regulated that the planting gangs are never short but at the same time never have so many plants that there is a danger of them drying out before planting. Normally plant supply keeps about one day ahead of the planting. In very dry areas it may be necessary to get the plants into the ground within hours of bringing them to the planting area, but in moister areas, or where shade or watering facilities are available, several days' supplies may be brought in advance which makes the organization of planting easier.

Plants for stumps should be well watered in the nursery before lifting and preparing the stumps. They should then be packed in bundles each containing a convenient number and wrapped in damp hessian for transportation. Though the stumps of many species are fairly tough and will stand a certain amount of desiccation, they should not be exposed to dry conditions unnecessarily before planting.

Planting

It is important to minimize disturbance of the roots when planting as this will result in increased casualties. The possibilities of root deformation resulting from use of polythene has been discussed in Chapter 11. Much more research on this aspect is required. Meanwhile, until convincing results are obtained from research, it is considered advisable, as a minimum precaution, to remove the polythene, at least over the lower two thirds of the length of the soil cylinder. Where termites are a problem, the retention of a "frill" of polythene, which is left projecting 1 to 1.5 centimetres above the soil surface, has been found to act as a deterrent. The object is to maintain a collar and avoid the deposition of soil over the pot during hand weeding — such untreated soil providing a bridge for termite activity. Pots or tubes may be slit with a sharp implement (razor blade or sharpened hacksaw blade) immediately before planting, but this should be done with great care to avoid disintegration of the soil cylinder, especially when using a friable soil mixture.

Planting is usually done in dug pits up to 30 centimetres cubed but if the postclearing cultivations have left the soil sufficiently well worked, then it is only necessary to dig a hole sufficiently large to take the soil cylinder. In termite areas the depth of the hole should be such that about 1 centimetre of the polythene is left projecting above the level of the soil as a deterrent.

Stumps are also usually planted in pits and if the species is susceptible to termite attack, dieldrin or aldrin powder is mixed with the soil

before refilling. If the soil is sufficiently permeable, stumps may be planted in a hole made with a crowbar or sharpened stick and well firmed in.

In all cases, it is essential that the surrounding soil is carefully firmed down round the plant immediately after planting, to avoid the formation of air gaps which might lead to drying out of the roots.

Fertilizing at or after planting

Most potting composts already contain fertilizers but these may be largely used up during the nursery stage. For some species further addition of fertilizers at the time of, or soon after, planting may be beneficial, especially where the soils are deficient in nutrients, as so many savanna soils are. Numerous experiments have been carried out with fertilizers applied after planting, often with conflicting results. This is perhaps to be expected when the great variety of soils and of species is considered, and it is difficult to deduce from them generalized recommendations either for species or localities.

The element most commonly in short availability seems to be phosphorus, and in experiments in which this element was added increases of growth were most often obtained. Nitrogen fertilizers, in the absence of adequate P, either in the soil or in the fertilizer, have frequently been deleterious and, even with sufficient P present, they usually do not give positive responses unless there has been adequate rainfall and generally moist conditions prevail. Potassium rarely seems to give positive responses, but there may be exceptions. The application of fertilizers sometimes causes increased mortality in newly-planted areas, possibly due to high concentrations of the fertilizer salts in the soil solution if adequate rainfall does not follow. The worst damage is to be expected after light rain followed by a dry spell, and where rains at planting time are unreliable it may be advisable to defer fertilizer application until the rains have become established and there is no danger of the soil drying out. The above are generalized indications, which may or may not apply to particular localities or species, and trials will have to be made locally until the best procedure is arrived at.

For instance, in Zambia, no fertilizers are given to pines after planting as they have been found to be unresponsive. *Eucalyptus "grandis"* and other eucalypts on the other hand are found to be very sensitive to soil fertility levels, and fertilizers are applied soon after planting. Formerly, an agricultural fertilizer, "Compound M" (NPK 9:12:9), was used at the rate of 85 grammes per plant but this has now been superseded, with economy in cost, by "High Concentrate D" (constitution of NPK 11:22:11) applied at the rate of 57 grammes per plant. This, for an espacement of 3 × 3 metres, works out at about 64 kilogrammes per hectare. The fertilizer is applied either in a slit 23 centimetres deep, 15 centimetres away from the stem of the plant, or it is spread on the surface of the soil and hoed in. It is not known whether the K content of the fertilizer has any beneficial effect but it is clear that, under Zambian conditions, eucalypts benefit from large doses of P (Allan and Endean, 1966).

In northern Nigeria, research into the fertilizer requirements of *Gmelina arborea* has shown significant height-growth responses to both P and N on poor soils, but no worthwhile responses on better soils. In some cases N applied alone was deleterious and there was a definite positive N × P interaction, combinations of these elements producing greater increase in height growth than the sum of the responses to each applied singly. Adequate moisture was found to be necessary to obtain a response from the N, which was applied in the form of urea. In general, fertilizers may cause casualties unless there is enough moisture in the soil to ensure that the soil solution is sufficiently dilute to avoid root damage. N fertilizers in particular do not benefit the trees unless there is plenty of moisture, and the best N effects are associated with wet seasons.

Fertilizer experiments with Neem (*Azadirachta indica*) in the Sudan zone of Nigeria gave similar results with N and P fertilizers.

Phosphate fertilizer is essential for pines in most of the savanna region of Nigeria. Otherwise there are either heavy casualties or there is a very uneven crop, with large numbers of stunted trees, the needles of which tend to wither at the tips. The symptoms are very similar to those caused by inadequate mycorrhiza inoculation, with the occasional trees growing well, and it is possible that the effect of phosphate is mainly on the mycorrhizae.

In Nigeria urea has been found to be injurious to pines, but ammonium sulphate has increased height growth if used in conjunction with phos-

phate. The increase is not very great however, and at present only superphosphate at 100 grammes per tree is used in pine plantations.

Many species of eucalypt are susceptible to deficiency of boron in the soil and many savanna soils are deficient in that element. The symptoms of boron deficiency are leaf deformation, serious die-back in the latter part of the dry season and frequently death. Even if these symptoms do not appear to a serious extent, there is reduction in growth. Experiments carried out in Zambia, Nigeria and elsewhere have amply confirmed the necessity of applying boron fertilizers in such cases. Not only are the symptoms of boron deficiency completely eliminated, but considerable increase in growth is usually produced. The original prescription in Zambia in plantations showing boron deficiency symptoms was 42 grammes of fertilizer borate (14 percent B) per plant, but it has since been found that this is insufficient to last a rotation and that at least 57 grammes are required on shallow soils in low rainfall areas and 144 grammes on the deep sands or in areas of high rainfall. The borate fertilizer is customarily applied in two bands, one on each side of the tree not closer than 45 centimetres from its base, and hoed or harrowed into the soil. A field application of 120 grammes per plant at a spacing of 3 × 3 metres requires 133 kilogrammes per hectare.

Replacement of casualties (blank-filling, "in-filling," "beating up")

Some mortality is usually to be expected after planting. This may be due to the use of weak planting stock, improper handling of plants, incorrect or unlucky choice of planting date, bad planting, adverse weather after planting, termite damage or damage by wild animals. But, with sturdy plants raised in polythene pots and adequate care that there is sufficient build-up of moisture in the soil before planting, the percentage of casualties is usually low.

There is frequently much doubt whether, in any instance, it is worthwhile attempting to fill in blanks. It is expensive, as all the planting operations have to be repeated for a relatively small number of plants. Moreover the replacements often do not take their place in the crop and may be later suppressed by adjoining trees of the original planting. Normally no replacements would be done in fast growing crops like eucalypts that close canopy in two years or less. If done at all, it should be in the early part of the first season. In slower growing crops planted at wide spacings there may sometimes be more justification, provided that the replacements are put in at a time that will give them every chance of early establishment and growth. Single blanks are usually not worth in-filling but, where large gaps are likely to be caused by the death of several contiguous plants, replanting may be essential. Such gaps complicate future management and provide foci for grass invasion and increased fire risk. In general, unless the overall mortality is high, it is usually inadvisable and uneconomic to replace casualties.

Plantations should be inspected three to four weeks after planting to assess the numbers and distribution of casualties and unthrifty plants likely to become casualties. If it is then decided to replace them, planting should follow immediately, i.e. as early in the rains as possible, so that the replacements have a good chance of becoming established and of putting on some growth before the beginning of the next dry season. It is rarely any use to replant in gaps in the later part of the rains as such plants do not have a chance of becoming established and are likely to be lost in the following dry season. In slow growing species or in areas planted at wide spacing, second-year replacement of casualties may be feasible and, for this, the assessment should be made toward the end of the dry season and the planting done at the beginning of the rains, as soon as planting in new plantations would normally start. Specially good nursery stock should be used so that the plants will have a chance of taking their place in the crop.

Tending

Weeding

In most countries and for most species the normal practice is to clean-weed or spot-weed the young plants until they have grown sufficiently to close canopy and suppress herbaceous vegetation. On an average this takes two to three years, but there is a great variation for different species and under different conditions. In savanna conditions, especially in the drier zones, the standards of weeding accepted as sufficient

for ordinary plantations in a high-forest climate are usually inadequate. The competition for moisture is much more intense, and complete clean weeding is generally essential, at any rate in the first season and usually in the second season as well. Cutting the weeds at ground level is also insufficient. They must be hoed out so that they are killed thus removing competition with the trees for water and nutrients, and this condition must be maintained until the tree crop is sufficiently well established to suppress further weed growth. In particular complete elimination of the savanna grasses is important, not only to remove root competition, but also as a fire protection measure. The maintenance of forest plantations in a locality which normally supports a fire-induced savanna vegetation depends not only on the initial elimination of the coarse grasses but also on the prevention of their reinvasion, by maintaining adequately dense canopies, or, if this is impossible, by continued eradication measures.

The species grown in savanna plantations vary in their tolerance of weeds. Nearly all are very intolerant in the early stages immediately after planting, but some, such as most *Acacia* and *Prosopis* species which rapidly send down deep tap roots, can, once established, tolerate a certain amount of surface weed growth. Some of the pines and species of *Callitris* are also fairly tolerant and recent experience in Uganda confirms this. Four species of pine and two of *Callitris* were planted in cleared *Terminalia* woodland (rainfall about 1 250 millimetres, five to six dry months, elevation about 1 400 metres). Under these conditions which included a heavy growth of *Imperata* grass, clean weeding was not found necessary for satisfactory survival and growth. In fact the trees had grown remarkably well during the early years without any weeding at all. This does not hold true for more typical savanna conditions. For example, clean weeding of pines is considered essential in the savanna areas of Nigeria. Nevertheless, the Uganda results do suggest that countries which are planting these species under similar conditions would be well advised to undertake systematic weeding trials to ascertain the minimum intensity of weeding necessary to obtain satisfactory survival and growth. Although clean weeding would almost certainly give the best results initially, such results may not be sufficiently superior or lasting (compared with those of lighter or no weeding) to justify the considerably heavier cost of clean weeding in these initial years, especially where that cost is carried through with compound interest to the end of the rotation.

On the other hand, certain species, such as the eucalypts, teak and *Gmelina*, are very sensitive to root competition for moisture and nutrients and there is no question that complete clean weeding is necessary for their establishment. Even at later stages of growth the presence of weeds, and particularly of grass, may cause a considerable fall-off in increment. Again, species which show tolerance to weed growth when cultivated on relatively favourable sites may need complete clean weeding when grown on drier sites, where conditions are near the limit for satisfactory survival and growth. Much more research is needed on the rooting habits of various species, as affecting their tolerance of weeds at different stages of growth and under different site conditions, so that the most economical weeding schedules for each can be determined. In the majority of cases, however, planting into a weed-free soil followed by clean weeding during the early establishment stages is found to be essential to success.

FIGURE 25. Two-month-old plantation of *Gmelina arborea* mechanically weeded with a rotavator at Nimbia, Nigeria.

(*Courtesy* J.K. Jackson)

Weed control is carried out by three main methods namely hand weeding, machine weeding and chemical control with herbicides. Frequently a combination of two or more of these methods is found to be most effective and economical.

Hand weeding is done where labour is plentiful and cheap and where the scale of operations is small enough to allow the weeding programme to be carried out without difficulty in the time

available. Hand weeding is unavoidable where close spacings are used which are too small to allow the entry of machines between the tree lines. Normally anything closer than 2.4 × 2.4 metres has to be weeded by hand. Where the ground is steep or rocky or where stumps are present, hand weeding is indicated and it is almost always necessary to supplement machine weeding by hand weeding round the trees or between the machine runs. The tool used is usually the native hoe of the locality to which the labourers are accustomed, but it is necessary to see that the tools are in good condition. In Zambia a blade of at least 12.5 centimetres and a handle at least 1 metre long is insisted upon. The weeds must be hoed out by the roots and this should be done when the weeds are very small. Not only is it much cheaper then, but moisture losses from weed transpiration are reduced to minimal amounts. It is particularly important to weed right up to the plants. The surface of the ground should be left as rough and loose as possible so as to catch the maximum amount of rain. In localities where soils crack badly on drying, a loose soil mulch left when weeding greatly reduces moisture losses from considerable depth in the cracks. On sloping ground the soil should be left in small ridges along the contours to check erosion and assist absorption of rainfall.

It is impossible to specify the number of weedings necessary as this depends on the species grown and the local conditions. In some cases, it may be possible to manage with only two weedings, one early in the rains and one at the end of the rains (assuming that planting has been done in weed-free soil), but more often three to six weedings may be necessary in the first season and two to five weedings in the second and third seasons. It is important that the last weeding at the end of the rainy season should be particularly thorough, so that the plantation enters the dry season in a weed-free condition.

Where taungya is possible (see Chapter 13, p. 113) considerable savings in weeding costs can be made, since the cultivators can be made responsible, as part of their agreement, for the adequate weeding of the planted trees. It is, however, necessary to ensure that the agricultural crops grown are of species that will not compete too severely with the tree crop and that they are not grown too close to the planted trees. Clean-weeded patches around the trees must be maintained. Their size will depend on climatic conditions and the species, both tree and crop, grown. Some reduction in tree growth is inevitable with taungya and is acceptable in view of the great savings in initial establishment costs.

It is impossible to give costs of hand weeding in savanna plantations, owing to the very great variation in conditions experienced. It is sufficient to say that, for small plantation schemes, especially where the weed growth is not too heavy, it can be as cheap or cheaper than machine weeding. Situations may arise when work has to be found for the local population and in such cases hand weeding will provide more employment than machine weeding and may be preferred, even when it is slightly more expensive.

Machine weeding is to be preferred in extensive plantation schemes or where labour is scarce or expensive. It has the advantages of much greater speed combined with deeper and more intensive cultivation of the soil. In large areas with long tractor runs (over 650 metres is desirable and the longer the better) it is usually considerably cheaper. It has, however, to be supplemented by hand weeding in spots around the planted trees.

The equipment used is usually a medium-powered wheeled tractor with a matched heavy duty cut-disc harrow mounted on the hydraulic linkage. In Zambia the equipment used has been a Fordson Major tractor with a Bentall heavy duty disc harrow. At a 2.7 × 2.7-metre spacing in pine plantations, a 2.13-metre disc harrow is used for weeding (Deveria, 1972), leaving a margin of some 30 centimetres on each side of the plant. A similar margin is left in the more widely spaced rows in eucalypt plantations. Some lateral roots are no doubt cut by the discs, and there is suspicion that damage to the roots from mechanical weeding may be providing entry points for a rot fungus attacking *Eucalyptus "grandis."* In northern Nigeria, Massey Ferguson tractors (TE20, MF35 and 65) with heavy duty reversible disc harrows are used for post-planting weeding.

In Zambia, after planting in clean-harrowed ground, tractor weedings are done at three-week intervals, each weeding being done at right angles to the previous one. This gives a programme of seven to eight tractor weedings in the first season, supplemented by spot weeding by hand

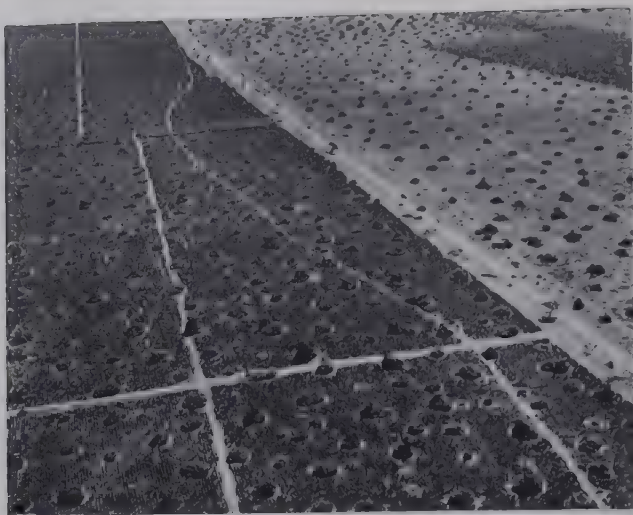


FIGURE 26. *Pinus kesiya* plantation near Ndola, Zambia. In extreme cases such as this, up to 25 percent of the total plantation area may be covered by termite mounds and their unplantable fringes. The mounds greatly reduce the efficiency of the mechanical weeding by shortening the length of tractor runs and also provide sources from which weed seed is spread.

(*Courtesy* Roan Consolidated Mines Ltd., Ndola, Zambia)

round the plants on a four-week cycle giving five or six spot weedings in the season. Emphasis is placed on the need for efficient first-season weedings as the more effectively they are done, the easier and cheaper will be the weeding regimes in subsequent seasons. The need for long clear runs has already been mentioned. Given these, each tractor should be able to weed some 6 to 8 hectares a day.

A recent investigation into the Zambian weeding procedure has suggested that economies can be effected and wear and tear of machinery avoided by reducing the number of weedings from eight (four in one direction and four at right angles at about three-week intervals) to only four in one direction (along the contours) and by hand weeding the residual unharrowed strips along the lines of plants instead of patch weeding round the plants. The effects of this will be (*a*) to eliminate unnecessary double harrowing over about 58 percent of the area, (*b*) to halve the numbers of machines and drivers required, (*c*) to avoid the severe pitching and shock-loading of machines as they go over the outside furrows when cross-harrowing, (*d*) to reduce erosion on sloping ground and to direct the water flow during rains to the rooting area of the plants, and (*e*) to increase the area of hand weeding between the harrowed strips from 1.2 to 1.8 square metres (12.8 to 19 square feet) per plant, i.e. a 50 percent increase. (The ground has to be walked over in any case.) Experiments are now being started to test these suggested changes in practice and the possibility of using chemical weeding methods in the residual unharrowed strips is also being investigated (Deveria, 1971).

For the second and subsequent seasons' weedings a smaller, narrow tractor and harrow may be used with advantage. Weeding is done each rainy season until the tree branches prevent the entry of the tractor between the rows, at which stage the tree crop should effectively suppress competing vegetation. In Zambia this period is normally:

For *Pinus kesiya*	— three seasons
Pinus merkusii	— four or five seasons
Eucalyptus spp.	— first season essential
Gmelina arborea	— two or three seasons

Priority is given to *Eucalyptus,* as it is found to be most sensitive to weed competition and it is necessary to keep the ground in *Eucalyptus* plantations completely clean at least through the first season.

Trials have been made using rotavators for weeding in plantations. Though the results were very satisfactory from the weed control point of view, the machines were not sufficiently robust to stand up to savanna conditions. It was found that rotavators can be used when the ground is too wet for disc harrowing.

Weeding, whether by hand or by mechanical methods, is an expensive operation, and the possibility of reducing the amount of weeding and hence the cost by the use of herbicides is being investigated. The work has not yet reached the stage of being able to determine whether chemical spraying of herbicides, either for preplanting cleaning of the soil or for postplanting weed control, is practical and economic under savanna conditions. For preplanting weed eradication, total (nonselective) herbicides can be used, provided they do not leave phytotoxic residues in the soil that will damage the trees that are subsequently planted. This would rule out substances such as sodium chlorate, but would permit the use of the various formulations of 2,4D or 2,4,5T in water or oil, or many of the more recently developed herbicides such as "paraquat" which are decomposed in the soil. These have been successfully used in many parts of the world for general clearance of vegetation and it is probable

that, if properly applied, with follow-up applications where a complete kill has not been achieved in the first application, the site will remain weed-free for a longer time after planting than is the case after manual or mechanical operations, thereby reducing the number of first season weedings.

Postplanting chemical weed control presents more difficult problems. Small-scale work can be done with knapsack sprayers or wheeled pressurized containers with spray lances using non-selective herbicides, provided that care is taken that none of the spray falls on the foliage of the planted trees. Devices are available that shield the tree while the weeds close around it are sprayed, and such methods have proved effective and economic in a number of countries. For large areas, however, it is necessary to resort to aerial spraying. This is usually done from helicopters but, if the terrain is suitable and landing fields can be prepared in the vicinity, fixed wing aircraft can do the job much more cheaply. For all aerial spraying, it is necessary to use selective weedkillers, that do not affect the planted trees but will destroy the weeds. Selective herbicides are known which will discriminate between conifers and broadleaved weeds, if used at the right concentration and application rate, but so far no satisfactory selective herbicide has been found that will discriminate between broadleaved trees such as eucalypts and broadleaved herbaceous or woody weeds. The whole subject of chemical weed control in savanna plantations is worthy of intensive research, as it has produced material economic benefits in other parts of the world. It seems probable, however, that its main application will be in rendering areas weed-free before planting.

Subsequent tending

These operations comprise climber cutting, thinning and pruning. Of these, climber cutting is seldom a problem in savanna plantations and needs no further mention. The operations of thinning and pruning in large areas of plantations can result in a very heavy work load and, for practical reasons, have to be kept to a minimum.

Thinning

Both thinning and pruning are closely associated with initial spacing. As already discussed, spacing must usually be a compromise between as wide as possible a spacing, in order to reduce planting costs and intertree competition in times of drought, on the one hand, and a close spacing, in order to induce early canopy closure, the suppression of weeds, the reduction of weeding costs and the natural pruning of side branches through shading, on the other.

In first-rotation plantations for rural requirements of fuel and poles, the ideal is to adjust the initial spacing so that the size and type of produce required is attained on a short rotation without any thinning. Produce from first thinnings is often unsaleable or uneconomic to extract. Furthermore, in coppicing species, such as many eucalypts, the stumps of the trees removed in thinning have usually to be poisoned so as to prevent competition from their regrowth affecting the increment of the residual crop.

Where produce of larger dimensions and higher quality is required, closer than final spacing is normal, and some thinning is then essential. The element of selection in thinning ensures that the increment of the final crop is concentrated on the best stems while the relatively close initial spacing reduces weedings costs. The timing of the first thinning is related to initial spacing and to site quality. In dry countries and on poor sites, first thinnings will have to be done at a smaller size than on higher quality sites, given crops of the same density. Crops planted at wide spacings can, however, be left longer before first thinning. In Zambia all planting of *Eucalyptus* is now done at 3.65 × 3.65 metres spacing. First thinning is done at mean top heights of 20 metres but this is for economic, not silvicultural,

TABLE 14. — *Eucalyptus* THINNING SCHEDULE FOR ZAMBIA [1]

At top height [2]		Thin to stems		Approximate expected age
Feet	*Metres*	*Per acre*	*Per hectare*	*Years*
65	20.0	200	500	3.6
85	26.0	133	333	5.2
		Clear fell		8.0

[1] Initial spacing 3.65 × 3.65 metres (12 × 12 feet); 750 stems per hectare or 304 stems per acre.
[2] Top height is here defined as the average height of the 10 percent of the crop trees having the largest diameters.

reasons, and there is a large body of evidence which supports the belief that first thinning in these crops could be postponed for several years, at least in the northern part of Zambia, without causing widespread losses.

The thinning schedule in Table 14 has been laid down for *Eucalyptus "grandis"* in Zambia, on a rotation of approximately eight years (Allan and Endean, 1966).

Previous plantings which were made at 3 × 3 metres (10 × 10 feet) are brought under a similar schedule.

For pines in Zambia grown for timber on a rotation of approximately 30 years, with intermediate yields being used for various specifications of poles, the following thinning schedule has been laid down (Allan and Endean, 1966).

TABLE 15. — *Pinus kesiya* THINNING SCHEDULE IN ZAMBIA [1]

At top height		Thin to stems		Expected age
Feet	*Metres*	*Per acre*	*Per hectare*	. . *Years* . .
46	14.0	240	722	7
65	20.0	140	350	12-13
85	26.0	90	220	19-20
		Clear fell		30

[1] Initial spacing 2.77 × 2.77 metres (9 × 9 feet); 1 300 stems per hectare or 527 stems per acre.

(In plantations established at a spacing of 3 × 3 metres, or 10 × 10 feet, the first thinning is done leaving 600 stems per hectare.)

Little information is available for thinning other species planted in savanna types. This is mainly because savanna afforestation is, in most places, a relatively recent development and plantations are not old enough to provide the data for drawing up thinning schedules. A very limited number of schedules has been produced, but unfortunately they have not been based upon, and do not mention, the "top height" of the crop at times of thinning, and hence give no guidance for thinning plantations of the same species on other sites of different quality and rates of growth.

Such a schedule, clearly empirical for the most part, has been suggested for teak grown under evidently very favourable conditions in the derived savanna in Nigeria (Barrott, no date). It is based on age with no reference to height and hence cannot be applied to other teak crops of differing rates of growth. It is interesting, however, as indicating the very heavy thinnings considered desirable in this species.

TABLE 16. — THINNING SCHEDULE FOR TEAK (*Tectona grandis*) PLANTED AT 2.7 × 2.1 METRES (9 × 7 FEET) SPACING IN THE DERIVED SAVANNA OF NORTHERN NIGERIA

Age	Trees/acre [1]	Trees/hectare [1]
0	691	1 705
6	450	1 112
10	220	544
15	130	321
20	80	198
25	60	148
30	45	111
40	35	86
50	35	86

[1] After thinning.

For *Gmelina arborea* in Sierra Leone the following thinning schedule has been given (Fox, 1967).

TABLE 17. — THINNING SCHEDULE FOR *Gmelina arborea* IN SIERRA LEONE

Age	Trees/acre [1]	Trees/hectare [1]
0	300	750
5	150	375
7-8	75	188
10	50	125
15	25	63

[1] After thinning.

No heights have been given so that the site quality to which this schedule refers cannot be determined.

This is not the place for a discussion of the theories of thinning control for optimum financial benefit. It is, however, pointed out that for maximum volume increment, combined with maximum size of individual trees, thinnings

should be designed to maintain a basal area in the stand which oscillates about the "limiting basal area" (LBA); that is, the minimum crop basal area that will yield maximum basal area increment. The determination of LBA for each species and site class is clearly a research priority as soon as crops become available for it — LBA is, fortunately, usually constant up to at least middle age — and it will be interesting to find out how it is affected by conditions in which soil moisture is limiting for a significant part of the year. Thinning regimes will then have to be worked out, taking into account such factors as the availability of markets for thinning produce of particular sizes and the price increment per unit volume expected for larger dimensions of the final crop. Control would be by specifying the frequency of thinning and the amount by which each thinning temporarily reduces the basal area of the crop below LBA. The paper by Bevege, 1967, contains a fuller discussion of basal area control of thinnings; this refers to slash pine in Queensland, but the principles apply generally to all thinning problems.

In carrying out thinnings, the aim is normally to get as even a spacing as possible and at the same time to remove the most defective and crooked trees at the earliest opportunity. In fast growing eucalypts, the first thinning can usually be done mechanically by removing entire rows (e.g. removal of one row in three in a plantation at 3 × 3 metres initial spacing would reduce stocking from an initial 1 110 stems per hectare to 740 stems per hectare). The advantage of mechanical thinning is cheapness, as marking is unnecessary and the felling in lines is simpler and quicker. Usually only the first thinning can be done this way, all subsequent thinnings being marked silviculturally. In Zambia, however, both *Eucalyptus "grandis"* and *Pinus kesiya* plantations are thinned silviculturally from the start on account of their poor form.

PRUNING

As in the case of thinning and for the same reason, there is little experience yet of pruning practice in savanna sawlog plantations. In pines a first pruning is often considered essential to allow access and as a fire protection measure to create a gap between floor and crown. In Zambia pruning schedules for pine and eucalypt plantations have been in operation for some years, but are now under review, on account of the unacceptably high work load they impose, especially in the case of pine plantations.

In pruning in *Pinus kesiya* plantations, the aim was to confine the knotty core of the lower part of the bole up to about 6.7 metres high to a central cylinder 10 centimetres in diameter. This involved the following schedule:

TABLE 18. — PRUNING SCHEDULE FOR *Pinus kesiya* IN ZAMBIA

Prune to		At top height		Expected age
Feet	*Metres*	*Feet*	*Metres*	*Years*
8	2.4	20	6.0	4
15	4.6	30	9.1	5-6
22	6.1	40	12.0	7-8

All trees were pruned and, where the pruning coincided with a thinning, the thinning was carried out first. Such frequent pruning in a very extensive plantation project was found to be unworkable. Moreover, due to height variation within the stand, the prescribed pruning was found to be much too severe on the smaller trees.

The following tentative revised schedule has now been prepared (Allan and Endean, 1966):

TABLE 19. — REVISED PRUNING SCHEDULE FOR *Pinus kesiya*

Prune to		At top height		Remarks
Feet	*Metres*	*Feet*	*Metres*	
7	2.1	35	10.6	Prune entire crop
12	3.7	50	15.2	Prune best 260 stems per hectare (or 105 stems per acre) only
25	7.6	53	16.2	

It should be noted that in Zambia pruning to 3.7 metres (12 feet) now means removal of every branch within 3.7 metres (12 feet) of the ground. This results in a clean bole varying between 3.7 and 5.2 metres (12 and 17 feet). The form of *P. kesiya* is in many cases extremely poor and in many compartments this higher and most costly pruning may not be justified. The last two prunings come between the first and second thinnings and are expected to take place at eight

and nine years of age respectively. The raise from 2.1 to 7.6 metres (7 to 25 feet) is always done in more than one pruning.

As regards pruning eucalypts, formerly no pruning was done, but now *E. "grandis"* crops are pruned to improve the quality of transmission poles and to prevent the formation of dead knots in timber to be used for joinery, boxes, etc.

Pruning to 3 metres is done at a mean top height of 10.5 metres and a second pruning to 6 metres is proposed at a mean top height of 20 metres, but no final decision has been made so far as to what further pruning if any should be done after the first 1 to 3 metres.

13. SPECIAL TYPES OF PLANTATION

Taungya

Taungya (or the system of raising plantations along with agricultural crops, in which the clearing of the site and the planting and tending of the trees is done wholly or in part by cultivators in exchange for the privilege of growing their agricultural crops) is, in its traditional form, only possible under certain limited conditions of land shortage that do not often occur in savanna areas. But where it is possible, the advantages in reducing the initial cost of plantations can be very great.

In the drier climatic types of the savanna region, taungya is not usually feasible for physical reasons. Not only is the rainfall usually too low and too irregular for successful agriculture, but in such dry conditions, the tree crop cannot stand competition of any agricultural crop for the small amount of soil moisture available. Taungya is only practicable where there is adequate soil moisture for both tree and agricultural crops at critical times of year. Tree species that are not so susceptible to root competition (see p. 106) are more likely to be satisfactory in taungya, though susceptible species such as teak and various eucalypts have been raised successfully in taungya, given adequately moist conditions.

The agricultural crops used also vary in the demands they make on soil moisture and hence in the degree of their competition with the tree crop. There seems to be little reliable information on this for crops that can be grown in savanna conditions, and even in other countries the suitability of particular crops for taungya is largely a matter of opinion and is not based on reliable experimental data. Some crops have the reputation of being highly competitive; e.g. sorghum (*Sorghum vulgare*), millet (*Eleusine coracana*) and pigeon pea (*Cajanus indicus*) are prohibited in some provinces of India as taungya crops, while they are accepted in others. Maize seems generally to be acceptable as also are cotton and dry rice, but much clearly depends on the climatic conditions. Some reduction in growth of the planted trees is inevitable with taungya, but is accepted as part of the price one has to pay for the much greater savings in initial establishment costs.

Where the physical conditions of the site are suitable for taungya but the populace is reluctant to take it up, it may be possible to obtain some of the advantages by some degree of departmental taungya. This can take the extreme form of all operations including the farming being done departmentally, the profits from the agricultural crop being set against the cost of plantation establishment or, more usually, it may be partially departmental and partially done by cultivators. For instance, in northern India, in conditions of dense high grass with scattered tree growth, greatly resembling African savanna, clearing of the site and preparing it for planting is done departmentally using heavy machinery. The cleared ground is then leased out to cultivators who manure it and grow a first-year crop of grain, no trees being planted this first year. In the second year the area is recultivated and cleaned and is planted with eucalypts and the cultivators are allowed to grow a crop of pulse such as *Cicer arietinum* leaving clear spots around the trees. The rent received from the farmers goes a long way toward meeting the plantation expenses. There are endless variations possible for such " semitaungya " which can be adapted to suit local conditions.

Enrichment planting

Enrichment planting, or the introduction of scattered trees of value into a matrix of low value forest, has been frequently tried. In high forest, with ample supplies of moisture, it has occasionally been successful, though it is always difficult and expensive. Under savanna conditions it is

rarely if ever successful and never economic. This is mainly due to the intense competition from the trees and grasses in the matrix. To carry out weedings and tending on a scale adequate to ensure reasonable growth of the introduced species is prohibitively expensive, and it is generally cheaper to clear the site and make plantations on clean ground. The subject of enrichment planting is mentioned here only to warn against it as a means of improving savanna woodland. Superficially the idea is attractive, and many have been tempted to try it. The results have usually been a considerable expenditure of money with little to show for it in the end.

Irrigated plantations

The irrigated plantations of the Gezira in Sudan merit special mention, as they are a striking example of the results that can be obtained in difficult circumstances with the aid of irrigation.

The Gezira is primarily a cotton-growing area, but the provision of firewood and poles is necessary for the people employed in the cotton-growing scheme. The soils are very difficult, alkaline black cracking clays, and the area is subject to severe summer drought; rainfall is about 400 millimetres per year and the climatic type is semidesert. However, with the aid of irrigation it has been found possible to create and maintain extensive fuel and pole plantations of *Eucalyptus microtheca*, which supply the needs of the local population.

E. microtheca was selected for planting because trials showed it to be the best suited to the heavy clay alkaline soils, and to the three and a half months dry period when irrigation water is not available. The original provenance used produced trees of poor form in the seedling crop which were very inferior as building poles. Much straighter poles are, however, obtained from the coppice crops of subsequent rotations.

Trials are now being carried out with other provenances of *E. microtheca* and with other species, mainly in order to obtain better form. The present Gezira working plan prescribes an initial eight-year seedling rotation followed by six-year coppice rotations.

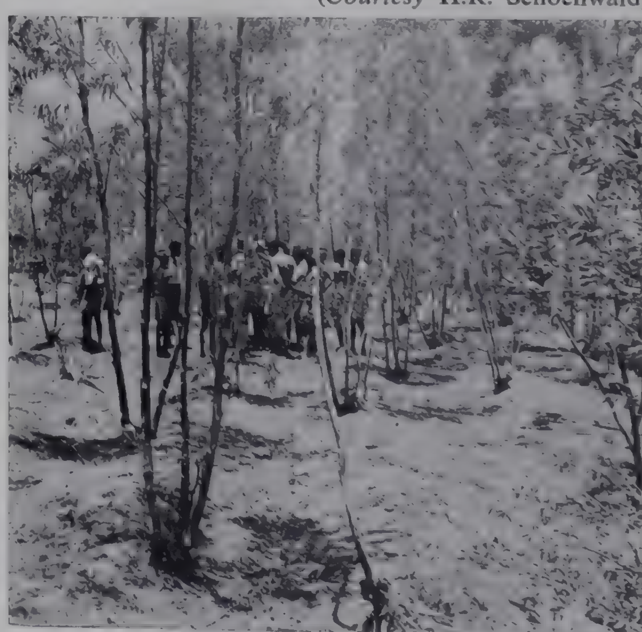
Yields of *E. microtheca* from the irrigated plantations are of the order of 25 solid cubic metres per feddan (= 1.038 acres) or 60 cubic metres per hectare at rotation age of eight to ten years but growth is very variable. It is probable that, with up-to-date techniques of site preparation and of planting and tending, higher and more uniform growth is being achieved now than in the earlier plantations established in the forties and fifties.

So far as methods are concerned, the plants are raised by direct sowing into polythene pots and are ready for planting after five to six months. The planting area is ploughed to form a series of low ridges, separated by the irrigation channels, and about 2.4 to 2.7 metres apart. The plants are planted 2.4 metres apart on the sides of the ridges, just above the irrigation water level. The plantations are irrigated at regular intervals of 14 days for the period July to mid-March, with a pause in October when cotton has priority and there is often a water shortage. No irrigation water is available from mid-March to the end of June, owing to the Nile Waters Agreement between Sudan and Egypt.

Apart from the irrigation, which adds the equivalent of about 640 millimetres of rainfall a year, the plantations are treated and managed in the normal fashion for *Eucalyptus* pole and fuel plantations and, as already mentioned, regeneration is by coppice.

Recently, a die-back appeared in some of the older plantations, the cause of which has been shown to be insufficient water.

FIGURE 27. Two-year-old coppice growth of *Eucalyptus camaldulensis* receiving periodic irrigation in Sudan. (*Courtesy* H.R. Schoenwald)



Irrigated plantations are also being established in other areas in Sudan. Where water is limited and is unavailable for parts of the year, *E. microtheca* is the favoured species as it stands periods of drought and great heat better than any other species so far tried. In the Khartoum greenbelt, which is irrigated throughout the year from the Khartoum sewage effluent, *E. camaldulensis* is used and grows very fast. A number of other species are being tried, of which *Conocarpus lancifolius* is the most promising.

The economics of irrigated plantations in Sudan are discussed in Part IV.

Bamboo plantations

Little has been done systematically to explore the potentialities of bamboo plantations in African savannas. Relatively few species of bamboo occur naturally in Africa, as compared with India, Burma and the Far East, where they constitute an important element in the forest economy and where there are species to suit a wide range of climates and soils. Most bamboos are naturally gregarious and hence would appear to be suitable subjects for pure plantations.

Bamboos have been described as the poor man's timber and they have a wide range of uses, such as poles for house building, furniture, screens, mats, agricultural poles, agricultural tool handles, spars for boats and a number of other purposes. They also produce excellent long-fibred pulp for high-grade paper making and in India are now extensively planted for this purpose.

The rate of production, when the clumps are fully developed, is high but, being monocarpic and often flowering gregariously there is a phase in the rotation when all the clumps may die simultaneously and the new crop may take six to ten years to come into production; but different species vary in this respect.

Harvesting is usually by selective cutting on a short rotation of a proportion of the older culms in each clump, leaving all the one- and two-year-old culms and a proportion of the older ones to nourish the rhizomes and maintain the productivity of the clumps.

There are only three bamboo species of importance which are common in Africa. Two of these, *Arundinaria alpina* and *Oxytenanthera abyssinica*, are indigenous and the third, *Bambusa vulgaris*, the "Golden bamboo," so called because of the golden stripes on the culms, is an exotic. The latter has been so widely planted throughout the world that it is now impossible to be certain of its origin, though it is probably Asiatic.

Arundinaria alpina, a nonclumping bamboo, grows at high elevations, and hence, although valuable and commonly used for house building and other purposes, is not suited for savanna planting.

Oxytenanthera abyssinica occurs pure in dense stands at lower elevations from sea level to 2 000 metres and is found under savanna conditions with a dry season of three to seven months. It tolerates a wide range of soils, even dry and shallow ones, on which it attains smaller sizes, but will not grow on very heavy clays or saline soils. This bamboo is used in quantity by the mining industry in Zambia, but so far sufficient supplies have been available from natural stands. In some parts of the country (e.g. parts of the eastern province) where poles and other materials are in short supply, *Oxytenanthera* is used in buildings, and attempts are being made to raise it artificially for this purpose as it is easier to manage than plantations of *Eucalyptus* (Greenwood, 1969).

Oxytenanthera has been established in small plantations on the silty river banks of the Blue Nile in Sudan. These were irrigated for the first year, and results were good. It was not so successful on the Gezira clays. The Blue Nile plantations are very remunerative, as there is a good market for the culms. It is very difficult to raise from cuttings, and the plots were raised from potted plants started from seed. In parts of Sudan, some plants of this bamboo produce seed nearly every year, and do not flower gregariously (Waheed Khan, 1966e).

Bambusa vulgaris is found in all tropical countries of the world and is cultivated for its tender young shoots, which are used for food. It has a wide ecological tolerance and is found in dense tropical forest habitats as well as in wooded savannas, and from sea level to 1 000 metres. It grows best on moist alluvial soils but is also found on the summits of hills with very poor soil. Compact clays and saline soils do not suit it.

It is a comparatively recent introduction to Africa and is found in Gambia, Ghana, Uganda, Tanzania (both on the mainland and in Zanzi-

bar), Mauritius and other countries. The most extensive plantations are in the Niari valley in Congo, but plantations are also found in Sierra Leone, and it is grown under irrigation in Sudan. *Bambusa vulgaris* has naturalized itself in river valleys in the wetter parts of the savanna region of Nigeria. Some experimental plantations have been made also.

It is quick growing, attaining 21 to 24 metres in height on good sites. The clumps are rather open due to the rhizomes growing up to 0.75 metres before producing new culms. The clumps become large, containing from 40 to 120 culms per clump. The culms are 7.5 to 10 centimetres in diameter, hollow, but strong and fairly durable. They make excellent poles. The wood is rather soft. It is a good pulping bamboo and is used for this purpose in Trinidad.

The following account of the technique of establishing plantations of this species in Congo is summarized from a paper by Groulez, 1967a. Stands are being planted in the Niari valley which is characterized by an annual rainfall of 800 to 1 500 millimetres in seven to eight months, a mean annual temperature of 25.5°C, a fairly even topography, a clay soil derived from the decalcification of calcareous schist, and *Hyparrhenia* and *Andropogon* high savanna with few shrubs.

After grubbing up the stumps and cutting back the grass the soil is ploughed and subsoiled, the grass roots being ploughed out. This complete preparation is very expensive and studies are being made to determine whether, on account of the wide spacing of the plants, cheaper partial preparation, e.g. in parallel strips, will suffice.

When the rains start in November, two cuttings, each with two nodes, are placed lengthwise in each planting site and covered with soil to a depth of 15 centimetres; these cuttings are planted either in planting holes or on the bottom of furrows made by a single-disc plough. The spacing recommended varies between 8 × 8 metres and 10 × 10 metres. The majority sprout within a month of planting, and an excellent take of 95 to 100 percent is obtained. Tending is done by machine, with usually three tendings during the year of planting and one the year after.

The actual cost of site preparation, including staking and pitting varies from 10 000 to 20 000 CFA francs per hectare (about \$40-\$80 per hectare or \$16-\$32 per acre) according to the type of preparation adopted. Preparation of cuttings comes to about 500 francs per hectare, transport 150 francs and planting 750 francs per hectare. Tendings cost about 6 000 francs per hectare. The total cost of establishment therefore comes to about 18 000 to 28 000 CFA francs per hectare (about \$72-\$115 per hectare or \$29-\$46 per acre) according to the kind of soil preparation adopted.

The characteristics of the clumps and the culms in a four and a half-year-old plantation planted at the earlier spacing of 6 × 6 metres (now found to be too close) are given in detail. To summarize, there are on average 31 culms per living clump, the range being 10 to 60 with only very few over 60. This is a reflection of the too close spacing, and a wider spacing will produce not only bigger clumps containing more culms but bigger culms. The average diameter was 4.16 centimetres. The yield at that age (four and a half years) from 6 × 6 metres spacing may amount to 66 tons of green culms per hectare (14 to 15 tons per hectare per year). The air dry weight, which is reached four months after cutting, is about 56 percent of the green weight.

Harvest cutting by the selection method is recommended, the best age for the first cutting being at six or seven years, with the selection cuttings removing about 50 percent of the standing material on a cycle of two to three years. This is expected to give a yield of about 33 tons green weight or 18 tons dry weight per hectare per year at four and a half years old from 6 × 6 metres spacing under the particular conditions of this trial. Higher yields are expected from plantations at wider spacings and with first fellings starting later. Further research is needed to determine the best time of starting exploitation, the optimum felling cycle, and the proportion of culms to be cut at each felling in order to produce the maximum yield of the required produce under any particular conditions of growth.

Little seems to be known about the flowering characteristics of *Bambusa vulgaris* in plantations, whether it is sporadic or gregarious and, if the latter, how long the flowering cycle is likely to be. There is scope for research into the potentialities of other bamboo species for planting in African savannas. *Dendrocalamus strictus*, the most widely used and cultivated bamboo of India, is an obvious candidate for trials and there must be many others. Few of them are likely to be as easy to propagate as *Bambusa vulgaris*, and propagation from seed, or from rhizome cuttings with a portion of stem attached, may be necessary.

14. PROTECTION OF PLANTATIONS

Insects

Probably the most serious enemy of savanna plantations is the termite. A few species, notably *Cassia*, *Gmelina* and some of the pines, appear to be relatively immune, but most eucalypts are particularly susceptible. Damage is most prevalent at planting and during the first few years of a plantation's life, but termites can kill quite big eucalypts, e.g. six to eight years old or more, if other conditions are adverse, for example if the trees are weakened by severe drought.

It is not practicable to eliminate termites from an area of any extent; nor, from an ecological angle, would it be desirable to attempt it. The best method of protection is to use vigorous and healthy planting stock and sound planting methods and, if particularly susceptible species are being planted, to give the plants a dose of insecticide either before or at the time of planting. Experience in various countries has shown that the vigour of the young plant is a very important factor in eliminating or reducing termite damage. For the more susceptible species, however, such as most eucalypts, vigour alone is not enough, at least in areas where termites are numerous; it must be supplemented by the use of soil insecticides.

Various insecticides and methods of application are used. The insecticides that have given the most consistently successful results are aldrin, dieldrin and chlordane. Effective results have been obtained with very small doses. In Uganda, a dosage of 0.28 grammes of active ingredient per plant, which at spacing of 2.4 × 2.4 metres costs about $4.20 per hectare, has been successful (Ball, 1970). In Zambia the standard practice is to apply 113 grammes of aldrin wettable powder in 13.6 litres of water (4 ounces in 3 gallons) to 600 plants in standard pots three times, namely one, two and three weeks after pricking out (Allan and Endean, 1966). This is now preferred to mixing the dry powder (2 percent dieldrin in this case) into the potting mixture at the rate of 0.77 kilogrammes per cubic metre of soil or 1.3 lbs per cubic yard. The purpose is to protect the plants when planted out in the field, and this method of adding the insecticide to the pots in the nursery by repeated watering has been found to be much more effective than adding it to the soil dug out of the planting pits, or dosing the hole at the time of planting, or watering the planting area with insecticide.

As mentioned under the heading of protection in nurseries (Chapter 11), these organochloride insecticides are persistent and permanently pollute the ecosystem. Research is urgently necessary to find effective substitutes that are ultimately broken down and rendered innocuous but, until that is achieved, it is essential to use the minimum quantities that will protect the plants adequately.

Apart from nursery pests (Chapter 11), other insect pests that requiere mention are the *Eucalyptus* snout beetle, the mahogany shoot borer and the iroko or mvule *Chlorophora* gall fly.

The *Eucalyptus* snout beetle, *Gonipterus scutellatus*, can cause serious damage to certain species, notably *E. maideni*, *E. viminalis* and *E. globulus*. These species are, however, hardly used at all in savanna afforestation. Damage is caused to a lesser extent to *E. camaldulensis* and *E. tereticornis*, both important savanna planting species, but the damage is not usually serious. Control is by a parasitic wasp, *Anaphoidea nitens*.

The mahogany shoot borer, *Hypsipyla robusta*, is a serious pest on most Meliaceae. It rarely kills the trees but, by damaging the leading shoot, causes severe distortion of the stem and, in some cases, multiple stems. Few close plantations of mahogany escape attack, and this pest is one of the main factors which limit the plant-

ing of mahoganies in the tropics, at least at close spacing. It is possible that better results might be obtained by planting at very wide spacings, but the economics of such planting are doubtful, as the yields per unit area will be low, while the cost of tending is likely to be abnormally high. No effective methods of control have so far been discovered.

The *Chlorophora* gall flies, *Phytolyma lata* on *C. regia* and *Phytolyma* sp. (incog.) on *C. excelsa* are serious pests and have so far precluded any successful close plantations of *Chlorophora*. No effective control measures have so far been devised. Various attempts have been made to control the pest silviculturally, by planting at wide spacing under light shade and with natural forest or nursery crops in between, to prevent the build-up of gall-fly populations, but these have not been successful on the whole. More recently, trials with systemic insecticides in Uganda have shown some promise on a small scale, but whether this will be effective or economic on a plantation scale remains to be seen. The possibility of avoiding attack by taking advantage of interspecific immunity was discussed in Chapter 7.

Fungi

Damage from fungi in nurseries, including damping off, has been dealt with in Chapter 11.

In plantations, root and butt rot of teak in the derived savanna and southern Guinea zones of Nigeria as well as in south Sudan, causes some concern. The cause of the disease is not yet known for certain, but research at the Savanna Forestry Research Station at Zaria, Nigeria, has shown that, while it occurs on a number of soil types, it is most serious on poorly drained soils where rooting tends to be restricted. This underlines the primary need for selecting well drained soils for teak plantations. A number of fungi have been isolated from attacked trees but evidence is building up that *Rigidoporus* (= *Fomes*) *lignosus* may be the primary parasite in this disease. Spread of the disease can be retarded by spraying the base of the tree with a solution of "Tillex," an organomercuric compound, but careful site selection with particular attention to good drainage and rooting depth appears to be the best means of avoiding the disease.

In the derived savanna, teak sometimes suffers from a die-back of the young shoots. This starts at the shoot tip and proceeds downward, sometimes causing the whole tree to die. A fungus of the genus *Stemphylium* has been isolated from affected shoots and may be responsible. (A second fungus, *Beltrania* sp., which was also found, is less likely to be causal, as this genus is primarily saprophytic.) This disease is so far unimportant in extent.

The cosmopolitan fungus, *Armillaria mellea* (Honey fungus or Bootlace fungus) occurs widely, usually as a saprophyte in the moister savanna zones, but, given favourable conditions for infection (e.g. root damage or weakened trees combined with a high inoculum potential in the soil), it may become actively parasitic, causing root and butt rot, and finally kill the trees. It has been reported as doing damage to the following species, among many others, used for savanna planting: *Acrocarpus fraxinifolius* (Kenya, Tanzania), *Araucaria cunninghamii* (Kenya), *Cassia siamea* (Uganda), *Chlorophora excelsa* (Ghana, Tanzania), *Eucalyptus citriodora* (Tanzania), *Gmelina arborea* (Nigeria), *Pinus caribaea* (Malawi, Mauritius, Tanzania), *Pinus kesiya* (Malawi), *Pinus oocarpa* (Zambia), *Pterocarpus angolensis* (Tanzania), *Tectona grandis* (Malawi, Nigeria, Uganda). In general, however, the damage caused by this fungus in the savanna regions is slight. There are no known methods of control except by maintaining plantations in a healthy vigorous condition and, at the time of site preparation, by removing and burning as much of the former woody growth as possible, so that the fungus has little opportunity to build up its population in the soil.

Gmelina arborea in Sierra Leone has suffered from extensive die-back and ultimately death of the whole tree at ages of 15 years and upward. No particular fungus could be identified as the primary pathogen. Initial symptoms were dying back of the roots from the tips, accompanied by shoot die-back above ground, and the damage was attributed to site conditions and competition.

Similar initial symptoms were experienced in India and Pakistan where, on waterlogged soils over clay, the tree has been attacked and killed by the *Gmelina* root-rot fungus *Poria rhizomorpha* at similar ages. There, the fungus spread to trees growing on adjoining well drained sites, and killed trees over an area of several hectares (Bagchee, 1953). This fungus has not been

reported from Africa, and is at present unimportant in India.

Phaeolus manihotis (syn. *Polyporus baudoni*) is reported as causing root rot in the Mamu river area of eastern Nigeria, but is not extensive. Root rot in small groups in Nigeria in 1966 has been attributed to *Rigidoporus lignosus*. So far, death from this cause is not extensive.

Root suffocation in poorly drained soils during the wet season is to be expected, and opens the way for infection through dead root tips by lethal fungi. This underlines the need for careful selection of well drained sites for *Gmelina*, if it is to be grown on rotations over about fifteen years, for the production of large sizes.

Eucalypts, so far, appear to be remarkably free from serious fungal diseases in the field. In Zambia, however, an unidentified heart rot has appeared in *Eucalyptus "grandis"* and may be potentially very dangerous.

Pines may suffer from various root rots and from needle infections, some of which can be serious, though less so in the savanna than at higher elevations where mist promotes spread of infection. A die-back of shoots of *Pinus oocarpa* has occurred at Nimbia, Miango and Afaka in Nigeria and has been associated with the fungus *Pestalotia* sp. The disease affects only a few trees in each area and does not appear to be serious. This fungus has also been found on *P. caribaea* and *P. radiata* and has been reported on *P. kesiya* in Zambia.

Overall, disease and insect problems have not to date proved serious in savanna plantations, but constant vigilance is needed to ensure early preventive action. Any country engaging in afforestation should employ, or at any rate have access to, expert forest pathologists and entomologists for continuous surveillance and assessment of the role and economic importance of diseases and pests as they appear. It is important that such investigation and assessment should take place as soon as the troubles are first spotted and before they attain serious proportions, otherwise considerable losses may be incurred unnecessarily.

Animals

Damage by animals in savanna plantations occurs from two broad causes, trampling and breakage by large animals such as elephant and buffalo, and browsing. The first is not a widespread cause of damage but may be serious locally and may become worse as the natural habitats of these large animals become reduced by man's encroachment on them for agricultural or forestry purposes. The usual method of control has been reduction of the excessive populations of the offending animals by shooting. Game moats or ditches have been used successfully as barriers in Kenya.

Browsing is a much more widespread form of damage and is caused both by wild animals such as antelope, and by domestic animals, especially goats. Control is commonly effected by means of fencing, supplemented by patrolling. Electric fencing has been tried in a number of areas but owing to the dry soil conditions that usually prevail in savanna areas over part of the year, it is apt to be ineffective unless a return wire is used. On the whole, for dry savanna conditions, barbed wire or thorn fences are probably the most effective means of control. Protection of predators such as leopard may be effective in controlling populations of browsers.

Damage from rats gnawing the stems above ground is encountered in some plantations in dense grassland. It is most damaging in young plantations, i.e. within the first two or three years after planting, but on the whole does not seem to be a serious trouble in most savanna conditions. The most effective method of control has been found in keeping the young trees well weeded and pruned, so as to expose the rats to their natural predators such as hawks, owls and snakes.

Fire

Fire is one of the greatest hazards to which savanna plantations are subject, and stringent precautions and countermeasures are necessary. These, as a rule, follow orthodox lines, *viz.*, the division of the area into small units by means of firebreaks and roads, the provision of a good look-out and rapid reporting system, liaison with local authorities and the public, and training of staff and labour in fire control work.

The elements of such measures are described in numerous textbooks and papers and need not be repeated here. There are, however, some problems that are of particular importance in the

fire protection of savanna plantations which merit special consideration.

First is the problem of grass. The natural vegetation of most savanna areas is a fire-induced grassy climax with an open canopy of scattered trees and shrubs. To maintain plantations in it requires the elimination of the grass and the creation of relatively fireproof grass-free conditions throughout the life of the plantation. The possibility of doing this economically depends largely on the completeness and efficiency of the grass eradication at the time of site preparation for planting. Any relaxation of standards of site clearance will result in rapid recolonization by grasses, necessitating expensive weedings to maintain tree growth and to remove the potential fire hazard of the grass.

As the plantations grow older there is the problem, especially in dry areas, that, in order to reduce excessive competition between the trees for soil moisture and to prevent casualties from drought, it is commonly necessary to thin heavily and keep plantations open. This encourages the reinvasion of grass, which may increase and persist throughout the rotation unless special eradication measures are taken.

This problem is most acute in light-crowned species and when crops are grown for timber on relatively long rotations. The invasive grass not only creates a fire hazard but, in its turn, competes with the trees for soil moisture. The fire danger is greatest in areas in which hunting is a customary pursuit, or which are close to cultivation, as the grass normally harbours game and there is a very strong incentive for the local people to burn it, either for hunting or to drive the game away from their crops.

How to deal with grass is a problem. Ideally, if it is fully eliminated at the time of site preparation, and is intensively weeded until canopy closure, and if a species that throws a relatively dense shade is grown, it should thereafter be possible to maintain a reasonably grass-free and fire-resistant plantation. More often this is not possible, and even though thinnings are regulated so that grass is reduced to a minimum, it may not be possible to avoid the development of a dangerously inflammable condition. An alternative would be to slash the grass, which will still leave a hazard in the form of cut dried grass, or to leave it and rely on intensive patrolling and propaganda to prevent firing, combined with an efficient organization for fire suppression.

A similar problem arises with enrichment planting and is likely to be more acute there, since, if the canopy is opened up heavily to encourage the maximum growth of the planted trees, grass growth will be correspondingly heavier. At the same time, the areas to be protected are likely to be larger and less divided up by roads and firebreaks and patrolling will consequently be more difficult.

Second is the problem of control burning. After the establishment phase is completed and the plantations have closed canopy, during the remainder of the rotation there is less fire danger from grass and more from slash left by thinnings and prunings. At this stage, where fire-resistant species have been planted, control burning within the plantations is the most effective means of fire control, but it requires very close supervision by experienced staff. At the same time, where plantations are surrounded by savanna, perimeter firebreaks should be maintained and the savanna grass should be control-burned periodically to prevent the entrance of fire into the plantations from adjacent areas.

An excellent statement of the problems and techniques for control-burning and other methods of fire control in savanna plantations in Zambia is contained in a report by Cheney, 1971. A summary of its most important recommendations is in Appendix 7.

Third is the problem of fire fighting methods. Owing to scarcity of water, it is rarely possible to fight fires using water, and control must be based on either beating out or on counterfiring. Both these are likely to prove more difficult in savanna conditions than in more temperate circumstances where they can be supported by water. It follows that, for effective fire control in savanna conditions, highly trained gangs and good direction and supervision are particularly important.

Fourth is the question of live firebreaks. It is common practice to plant live firebreaks but unless the firebreak species is itself usable, a great deal of ground, sometimes as much as 10 percent, may be rendered unproductive. The species normally planted for firebreaks are commonly usable for poles and fuel but no really satisfactory firebreak species has been found that can be used for sawlogs. The species commonly planted, such as eucalypts of various kinds, can be used for poles or fuel but the management of narrow firebreaks for these purposes in timber

plantations poses certain problems. A clean floor must be maintained within the firebreak if it is to serve its purpose effectively, and removal of litter entails extra cost.

In consequence, some forest authorities are reconsidering the advisability of planting firebreaks and their thoughts are turning more to an intensive network of narrow clear firebreaks.

Part IV

ECONOMIC ASPECTS

Very little published information is available on the economics of savanna plantations. There are some scattered data on costs of establishment and tending plantations, but such data have been collected in so many different ways and there is so much variation in the content of the costings, that it is often impossible to make meaningful comparisons between costs in different localities, or to compare the costs of different plantation techniques.

Because savanna planting has only developed recently, few plantations have been through a complete rotation and there are even fewer data for yields and financial returns. Markets for produce often have not had time to develop and become stabilized, and the prices obtained for produce may not be representative of what may be expected in the future. Figures of revenue are usually given in local currencies without conversion to a common currency, which further adds to the difficulty of making comparisons.

Hence, at the present time, the estimation of profit and loss on savanna planting is usually an unreliable and highly speculative exercise. Nevertheless it would be wrong to say that it cannot or should not be attempted. Even if the results of such calculations are unreliable and may include a wide margin of error, it is important that an effort should be made to get some idea, however rough, of the degree to which savanna plantations can be considered "economic." In this connection, it is necessary to define "economic" in relation to the particular circumstances in which the plantations are being raised. Often there are social and other benefits which may be important along with, or even sometimes outweighing, purely financial considerations, though, in such cases, the opportunity costs involved should be known. This point is discussed further in Chapter 17.

15. COSTS

The costs of creating plantations in savanna areas tend, on the whole, to be higher than those for more conventional plantations on normal high-forest sites, though this need not always be the case. Clearing of existing vegetation may sometimes be less, owing to the tree growth on the site being lighter and more scattered. Site preparation and soil working have usually to be much more thorough in the drier savanna areas and may cost more. Similarly, weeding and grass control may have to be more intensive and hence more expensive. Conditions, however, vary widely and, where it is possible to employ taungya methods, very great economies can be achieved.

Many assessments of the costs of making plantations are now available and from most of them some useful information can be extracted, such as the detailed outputs per man-day when carrying out different operations. Where the work content of different operations is described in detail and broken down into ultimate units, useful comparisons can be made and attention drawn to the differences in relative efficiency between similar jobs carried out in different localities. This can be valuable in indicating where improvements in practice and economy in costs can be made. Such comparisons are also of help in determining the outputs that may be expected under the most efficient methods and in providing data for fixing piece rates.

Unfortunately, in the majority of costing studies reported, the job content of different operations is not adequately described, nor is it in any way standardized, so that much of the value of the costing is lost. There is a real need for standardization of the scope of the operations and the methods of recording costing studies and it would be a great boon if this could be done, preferably on an international basis, by designing and issuing standard schedules for the purpose.

The following examples illustrate these points. They are divided into nursery costs and plantations costs.

Nursery costs

Two recent examples are given, namely one from Zambia and one from Nigeria. The former is for a large-scale, highly mechanized nursery raising pine seedlings in which intensive work study has, over the years, led to a good level of efficiency. The other is a detailed study made by the Nigerian Federal School of Forestry, Ibadan, for raising eucalypt seedlings. In both cases, only the unit quantities of labour and materials are given.

ZAMBIA. UNIT QUANTITIES OF MATERIALS AND LABOUR FOR PINE PLANTATION AT 10 × 10 FEET (3 × 3 METRES) SPACING [1]

These figures are based on work study quantities and standard times, applied to the current nine-hour day. A unit figure of 100 acres (40 hectares) net area is used. Plants needed in the nursery: 50 000. For each 100 acres (40 hectares) of planting, therefore, the following *estimates* of labour and materials will be required.

Soil

Volume	16 cubic yards (12.5 cubic metres)
Scuffling	0.11 acres (0.045 hectares), 0.7 man-days
Bulldozer	37 standard minutes + driver
Sieving	2 man-days
Transport and loading (one seven-ton Albion tipper lorry and driver)	180 minutes
Labour (four men loading for 0.33 days each)	1.32 man-days

[1] Allison, 1970.

Pots
(50 000)

Filling and setting out	4.5 man-days
Sterilizing	1.5 man-days
Bromide	10 lbs (4.54 kilogrammes)

Note: These are "minipots" 4 inches (10 centimetres) long and 6 inches (15 centimetres) in circumference.

Sowing
(Two seeds per pot)

Sowing	11 man-days

Fungicide treatment

Labour, Zineb drench	4 man-hours
Zineb for drench	5.4 lbs (2.5 kilogrammes)
Labour for 4× Zineb sprays	2 man-days
Zineb for spraying	6.3 lbs (2.9 kilogrammes)
Total Zineb	11.7 lbs (5.4 kilogrammes) approx.

Blanking and singling
(Two seeds per pot sown, germination 60 to 80 percent)

Labour	4 man-days

Watering

Irrigation pump — diesel fuel	4 gallons (18 litres) approx.
Labour	1.5 man-days approx.

Fertilizing

"Welgro"	50 lbs (23 kilogrammes)
Labour	1.5 man-days

Nursery weeding

"Gramoxone"	0.1 gallons (0.45 litres)
Labour	0.5 man-days

Root pruning and grading
(Allowing four root prunings of 4 man-days each)

Labour	16 man-days

Boxing
(Allow a stock of 300 at start of season)

Labour	8 man-days

Loading

Labour	1 man-day approx.

Summary
Unit quantities for 100 acres (40 hectares) at 10 × 10 feet (3 × 3 metres) spacing:

Labour	56 man-days approx.
Bulldozer plus driver	37 standard minutes
Albion seven-ton tipper plus driver	0.33 days
Pots	50 000
Methyl bromide	10 lbs (4.54 kilogrammes)
Zineb	11.7 lbs (5.4 kilogrammes)
Diesel fuel for irrigation pumps	4 gallons (18 litres)
"Welgro" fertilizer	50 lbs (23 kilogrammes)
"Gramoxone" weed-killer	0.1 gallons (0.45 litres)
Boxes	30

By way of contrast, the study in Table 20 of the hypothetical requirement of nursery work for a 1 200-hectare fuel plantation model for *Eucalyptus* sp. in Nigeria, with a 120-hectare annual planting area at 3 × 3 metres' spacing is interesting (Nigeria, Savanna Forestry Research Station, 1971a).

This works out at about 383 man-days per 50 000 pots raised, or 11.4 man-days/hectare (4.6 man-days/acre) supplied with plants. This, of course, is not the full cost of the plants, as the following items have not been included: cost of seed, cost of germination boxes, polythene pots, fertilizers and insecticides and such overheads as supervision, general departmental overheads, and the running costs and depreciation of vehicles and of the irrigation system. On the other hand, preparation of potting mixture can be considerably cheapened by the use of a small cement mixer, the standard size of pots has now been reduced to 15 × 25 centimetres, and seedbox preparation and pricking out are now largely eliminated by direct sowing into the pots.

In the Zambian costing, the cost of seed is also not mentioned, nor are general overheads. The length of the working day (nine hours) is stated in Zambia but not mentioned in the Nigerian estimate which leaves an element of doubt. Nor is it clear in the Nigerian estimate whether the collection of topsoil from the forest is included and to what extent this is mechanized.

Comparisons between costings are valuable in showing up differences in techniques and possibilities of economy, though it should be noted that in the present instance the Zambian figures pertain to pines, while the Nigerian figures are for eucalypts. As regards techniques, in the Zambian estimate, mention is made of soil ster-

TABLE 20. — LABOUR REQUIREMENTS FOR *Eucalyptus* NURSERY IN NIGERIA

Task	Output per man-day (except where man-hours are stated)	Man-days required
Mixing soil and filling germination boxes (100 boxes)	50 boxes	2
Seed sowing (2 g in 100 boxes)	100 boxes	1
Watering twice a day for 3 days	100 boxes per hour	1
Preparation of potting mixture for 180 338 pots, 25 cm long × 25 cm circumference (10 in. × 10 in.) at 1 headpan per 12 pots	45 headpans	334
Filling 180 338 pots	600 pots	300
Packing 180 338 pots	1 500 pots	120
Pricking out	600 seedlings	300
Watering by hand twice a day for 7 days	5 000 pots per hour	63
Irrigation over 4-month period	1 man for 1 hour/day	16
Weeding and beating up, 2 weedings of 180 338 pots	1 500 pots	240
Total man-days required		1 377

ilization, fertilizing, root pruning, grading, post-germination fungicidal treatments and the use of insecticides in the soil mixture as a protection against termites after planting in the field. These do not receive specific mention in the Nigerian costing, though some of them may be done. This raises the question whether, if Nigeria is able to do without any of them, could not Zambia make savings by omitting them, or alternatively, if Zambia finds after years of research and experience, that they are desirable or even essential, might it not be advantageous for Nigeria to introduce them? These are matters for critical comparative research under local conditions.

As regards possible economies, the contrast between the highly mechanized operations in Zambia and the greater hand-labour content of the work in Nigeria suggest lines for investigation.

The biggest differences however are

(*a*) the use of minipots in Zambia (a Zambian minipot contains one seventh the volume of a Nigerian pot), and

(*b*) the practice of direct sowing into the pots in that country, as compared with the traditional sowing in germinating beds and pricking out into pots in Nigeria.

If Nigeria were to find that it was possible to adopt these two Zambian practices under their local conditions a direct saving of some 730 man-days (net) or over 50 percent saving in the labour content of their nursery work would immediately accrue, not to mention further material savings in transport of plants to the field at planting time.

Most countries develop their nursery techniques locally and to a great extent independently, and the above analysis of differences between Nigerian and Zambian practice is intended to illustrate the benefits that may be gained by comparative study of techniques and their costing in different countries. Only this, supplemented by research where necessary, will enable the most efficient methods to be determined for any particular locality. But, in order to be as useful as possible, the costings must be made in standardized units and in a standardized way that can make meaningful comparisons possible.

No attempt has been made to translate the above costings into money. This can only be done accurately when full details of wages, unit costs of machinery, costs of materials, overheads, etc. are known.

Also, with the current rate of inflation, costs expressed in money terms are only relevant to the year in which the data are collected.

In order, however, to get some idea of the relation between the cost of plants and the other establishment costs reported in the following section, it may be noted that, very roughly (assuming a current wage rate of 6 shillings ($0.85) [1] per day for manual workers), plant costs work out at about £3.0.0 to £4.10.0 per acre, or $21 to

[1] Rate of conversion adopted: £1 (Nigerian) = U.S.$2.84.

$32 per hectare for polythene pot plants and about £1.15.0 to £2.2.0 per acre or $12 to $15 per hectare for stump plants grown in nursery beds.

The cost of plant supply is relatively small compared with the total cost of establishing plantations, and money spent in producing good sturdy plants with a high survival and growth potential is generally well recouped in later savings in casualty replacement, lower weeding costs and faster growth. Thus, the value of nursery techniques and of economies in nursery costs must be judged in relation to the success of the plantations.

Plantation costs

Such accounts of plantation costs as are available suffer from the same defects as nursery costs, only to a greater extent. The few instances given below are mostly fragmentary and incomplete and, while they may be of local value, they are, in general, not in a form that makes valid comparisons between operations in different countries possible. It may be noted that, in contrast to the nursery costs quoted above, plantation costs are available only in monetary terms. In the absence of data on wage rates, machine costing rates per hour, etc., only crude comparisons are possible from one country to another. The figures do, however, illustrate the wide variation in the costs of creating plantations under different conditions in the savanna zone. The largest component of this variation is in clearing and preparation of the site, but considerable variation is also found in the unit costs of other inputs and in techniques for doing similar jobs under not too dissimilar conditions.

One of the better documented costings is the account by Barrott, 1969, of the experimental timber plantation project at Nimbia in the North Central State of Nigeria. This project was for 120 hectares per year, largely of teak at a spacing of 2.7 × 2.1 metres, or 1 705 trees per hectare. Details of the vegetation and the cost of clearing have already been given in Chapter 9, p. 85-86, but the cost figures are repeated here for completeness (Table 21). Clearing was done by hand and by contract, hence the actual number of man-days used is unknown, but wage rates at that time were about six shillings ($0.85) per day.

TABLE 21. — COSTS OF ESTABLISHING TEAK PLANTATIONS AT NIMBIA, NIGERIA

Operation	Costs per unit area of 691 trees per acre			
	Polythene pot plants		Stumped plants	
	£ per acre	$ per hectare	£ per acre	$ per hectare
LAND PREPARATION				
Clearing	12.10.0	87.50	12.10.0	87.50
Windrowing	4. 0.0	28.00	4. 0.0	28.00
Burning	6.0	2.10	6.0	2.10
Additional clearing	17.0	5.90	17.0	5.90
Pioneer ploughing	3. 0.0	21.00	3. 0.0	21.00
Total preparation	20.13.0	144.50	20.13.0	144.50
ESTABLISHMENT				
Nursery stock	4. 4.0	29.40	1.18.0	13.30
Planting	1. 8.0	9.80	1. 0.0	7.00
Seedling transport	1. 2.0	7.70	10.0	3.50
Cultivation 3 years	7.15.6	54.30	7.15.6	54.30
Fire tracing 3 years	1. 6.0	9.10	1. 6.0	9.10
Total establishment	15.15.6	110.30	12. 9.6	87.20
Total preparation and establishment	36. 8.6	254.80	33. 2.6	231.70
LOCAL OVERHEADS	11. 0.0	77.00	11. 0.0	77.00
Grand total	47. 8.6	331.80	44. 2.6	308.70

This plantation is considered somewhat atypical for Nigerian savanna conditions, as the initial vegetation was denser and the trees larger than average, so that in most savanna areas the cost of initial site preparation would be lower.

In second and subsequent rotations it has been estimated that clearing would cost $45.50 per hectare less and there would be about $11.50 per hectare more revenue from firewood on clearing the site. The adjusted total costs would be about $275 per hectare and $254 per hectare for plantations raised with pot plants and stumps respectively.

The above is just one example. Costs will be

less on sites with lighter vegetation, as is usually the case, and for "Doka" woodland in Nigeria, Nash, 1968, has given the following probable range of costs for the mainly mechanized operations of clearing, ploughing and cultivation as in 1968.

TABLE 22. — COST OF SITE PREPARATION IN NIGERIA

	Maximum cost		Minimum cost	
	£ per acre	$ per hectare	£ per acre	$ per hectare
Site clearing	18. 0.0	126.00	8 0.0	56.00
Windrowing	7. 0.0	49.00	2. 0.0	14.00
Ploughing	3. 0.0	21.00	3. 0.0	21.00
Discing	15.0	5.30	10.0	3.50
Cultivation (2 years)	2.10.0	17.50	2. 0.0	14.00
Total	31. 5.0	218.80	15.10.0	108.50

Studies are being made in Nigeria (Allan, 1971) on machinery outputs under different conditions. The conclusion so far is that the ideal combinations of tractors and implements for the various operations have not yet been arrived at, but it is clear that in the *Isoberlinia doka* woodland, clearing by using bulldozers is considerably cheaper than hand clearing and that costs can be reduced still more by chaining.

Endsjø, 1967, has assembled costs of establishing plantations in the Sudan zone of Nigeria. On former farm land first-year costs (excluding overheads) were $77 per hectare and second-year costs $49 per hectare. On savanna land (not described but presumably dense grass with scattered shrubs and small trees) first-year costs were $91 to $119 per hectare; second-year costs were not available but, if one assumes that they were approximately the same as on old farm land and that third-year costs were about $21 per hectare, then total costs (pre-1967) would have been of the order of $140 per hectare for old farm land and $160 to $190 per hectare for savanna land.

The scale of operations affects the costs. In Zambia, for instance, with denser woodland than at Nimbia, Allan, 1967b, gave a cost of $27.10 to $27.80 per hectare for clearing, using D-7 tractors with chains as described in Chapter 9.

This much lower cost was possible on account of the larger annual plantation areas and the possibility of arranging their shape so that the tractor had a relatively long run, usually over a mile (1.6 kilometres) so as to reduce the proportion of turning time. The costs of ploughing and harrowing were similarly reduced.

The following maximum and minimum costs of the mainly mechanized operations in the Zambia project quoted by Allan, 1967b, illustrate this, but it is to be noted that intensive work study in Zambia has resulted in considerable further reduction since then.

TABLE 23. — COST OF SITE PREPARATION IN ZAMBIA

	Maximum cost		Minimum cost	
	£ per acre	$ per hectare	£ per acre	$ per hectare
Knocking down	3.19.6	28	3.17.5	27
Windrowing	5. 2.0	36	4. 4.0	29
Cleaning up [1]	6.11.5	46	3.11.11	25
Ploughing	1.16.7	13	1.14.10	12
Discing	10.2	4	8.1	3
Total	17.19.8	127	13.16.3	96
First weeding regime [2]	4. 7.11	31	3. 3.9	22
Second weeding regime	4. 9.10	32	2. 9.8	17
Total	26.17.5	190	19. 9.8	135

[1] Largely a hand operation, and can be the most expensive item.
[2] Includes hand spot-weeding. See also Chapter 12 for later ideas.

Economies of scale are also reflected in the latest Nigerian estimates of anticipated establishment costs of savanna pine plantations (Table 24), assuming an annual planting area of 400 hectares and the use of improved techniques (Allan, 1973a). In comparing these estimates with earlier figures, it should be noted that the effect of inflation offsets economies of scale.

Similar estimates of anticipated plantation costs of savanna eucalyptus plantations in Nigeria have been projected to cover the first four

Table 24. — Estimated establishment costs of pine plantations in Nigeria

Direct costs			
Item	Costs		Year
	£N/hectare	$/hectare [1]	
Survey	0.50	1.40	0
Roading	6.00	16.80	0
Knocking down	3.50	9.80	0
Firewood revenue [2]	(+8.50)	(+23.80)	0
Heaping and burning	5.50	15.40	0
Ploughing	8.00	22.40	0
Harrowing	5.10	14.28	0
Raising plants	10.50	29.40	0
Planting	20.00	56.00	1
Fertilizing	7.00	19.60	1
Mechanical cultivation	8.00	22.40	1
Mechanical cultivation	6.00	16.80	2
Mechanical cultivation	6.00	16.80	3
Hand cultivation	2.00	5.60	1
Beating up	8.40	23.52	1
Total to year 3 if firewood saleable	88.00	246.40	
Total to year 3 if firewood unsaleable	106.00	296.80	
Allocation of overheads per hectare			
	8.50	23.80	0
	8.50	23.80	1
	4.25	11.90	2
	2.10	5.88	3
Total overheads per hectare to year 3	23.35	65.38	

[1] Exchange rate used: £1 Nigerian (N) = U.S.$2.80.
[2] Where firewood cannot be sold there is no revenue and an additional windrowing cost of £N9.50 ($26.60) has to be included.

rotations, assuming an annual planting area of 200 hectares and a six-year coppice rotation (see Table 26, p. 131).

In drier areas, where the natural vegetation is relatively sparse, clearing costs may be expected to be less. This, however, may be counteracted by having to deal with highly compacted and sometimes rocky soils requiring very heavy machinery for clearing and cultivation. An example of this type of situation from outside the savanna region is that of eastern Morocco. There, the subsoiling or "rootage" operation was done by D-8 Caterpillar tractors of 230 hp, working in the compacted upper profile of the soil at the rate of about $^1/_3$ hectare per hour, while the routine cultivation by a 50-hp wheeled tractor was at the rate of about $^1/_2$ hectare per hour. The total cost of all operations including overheads was of the order of $152 per hectare and was made up as follows:

Table 25. — Cost of site preparation in eastern Morocco

	Percentage	Dirhams per hectare	$ per hectare	£ per acre
Rootage	32.2	248	49	7.0
Preplanting cultivation	13.0	100	20	2.9
Postplanting cultivations (two)	8.1	62	12	1.7
Total mechanized operations	53.3	410	81	11.6
Hand weeding for two years	13.0	100	20	2.9
All other operations (plants, planting, overheads, etc.)	33.7	260	51	7.3
Total establishment cost	100.0	770	152	21.8

Note: Exchange rates used: 5.06 dirhams = U.S.$1.00 = £0.352.

Intensive costings (Goujon, 1963) of plantation establishment, including maintenance for three years, have been quoted for five different soil types in Morocco. These varied from $147 per hectare on sandy soils with a few dwarf palms ("Marmora forests") to $245 per hectare on compacted, very hard soils requiring two very difficult runs. Similar compacted sites may occur in the drier parts of the savanna south of the Sahara.

TABLE 26. — ESTIMATED COSTS OF *Eucalyptus* PLANTATIONS IN NIGERIA

DIRECT COSTS

Item	Costs		Year	Cumulative cost to age 25	
	£N per hectare	*$ per hectare* [1]		*£N per hectare*	*$ per hectare* [1]
Survey	0.50	1.40	0	0.50	1.40
Roading	6.00	16.80	0	6.00	16.80
Road maintenance (per year)	1.00	2.80	0 to 25	25.00	70.00
Knocking down	3.50	9.80	0	3.50	9.80
Firewood revenue [2]	(+8.50)	(+23.80)	0	(+8.50)	(+23.80)
Heaping and burning	5.50	15.40	0	5.50	15.40
Ploughing	8.00	22.40	0	8.00	22.40
Harrowing	5.10	14.28	0	5.10	14.28
Raising plants	10.00	28.00	0	10.00	28.00
Planting	17.00	47.60	1	17.00	47.60
Fertilizing	11.50	32.20	1	11.50	32.20
Mechanical cultivation	8.00	22.40	1	8.00	22.40
Mechanical cultivation	4.00	11.20	1	4.00	11.20
Hand cultivation	2.00	5.60	2	2.00	5.60
Protection (per year)	4.00	11.20	0 to 25	100.00	280.00
Coppice thinning	1.00	2.80	7, 13, 19	3.00	8.40
Total to year 25 if firewood saleable				200.60	561.68
Total to year 25 if firewood unsaleable				218.60	612.08

ALLOCATION OF OVERHEADS PER HECTARE

				Overheads to age 25	
	13.50	37.80	0	13.50	37.80
	13.50	37.80	1	13.50	37.80
	10.80	30.24	2	10.80	30.24
	2.70	7.56	7	2.70	7.56
	2.70	7.56	13	2.70	7.56
	2.70	7.56	19	2.70	7.56
	2.70	7.56	25	2.70	7.56
Per hectare per year	0.30	0.84	0 to 25	7.50	21.00
Total overheads per hectare to year 25				56.10	157.08

[1] Exchange rate used: £1 Nigerian (N) = U.S.$2.80.
[2] Where the firewood cannot be sold, there is no revenue and there is an additional windrowing cost of £N9.50 ($26.60).

The above examples illustrate the variability of costs of establishment in different circumstances. Many others could be quoted, but most of them are even less informative on account of incompleteness of detail. Recorded costs range from about \$20 to \$250 per hectare or more. This wide range reflects variations in the extent and difficulty of site preparation, the unit costs of inputs and in the accounting methods used. Before a given figure becomes of much analytical value, either for comparing the costs of different techniques or for assessing the economic results of plantations, it needs to be specified, on a uniform and comparable procedure as to:

(*a*) the objective of the plantation (e.g. whether for fuel, poles, timber or other raw materials, separately or in combination);

(*b*) the amount and difficulty of land clearing involved, (the density and size of the vegetation to be cleared and any special soil factors affecting rate of progress and the types of machines needed);

(*c*) the size of the annual programme (as affecting the scale of investment in machinery, etc.);

(*d*) the current rates (both daily and for piece-work) of payment for hand labour;

(*e*) details of the methods of costing units of input, (e.g. the hourly rates for different machines, etc.);

(*f*) the output of these machines working on specific operations under the conditions of the plantation;

(*g*) plantation details, spacing, species and kind of planting stock and its cost, method of planting, method of weeding, etc., casualty percent and cost of replacements etc., and any initial protection measures against fire, pests and diseases, with their costs;

(*h*) the extent to which special methods and systems have been used to reduce costs (e.g. taungya for reducing initial clearing and other costs, with details of the taungya agreement insofar as they affect the costs; the employment of charcoal burners for clearing up the debris after "knocking down," etc.);

(*i*) the year for which the figures are relevant and any particular circumstances in that year (e.g. unusual drought or floods, etc.) that affected the costs;

(*j*) the length of the establishment period;

(*k*) the exchange rate in the year in question for converting costs in national currencies to a common unit;

(*l*) any incidental revenue (e.g. from sale of fuel) that may be set against the costs of establishment.

In the post-establishment stage there are further costs to be taken into account, namely:

(*m*) costs arising at irregular intervals such as fertilizing, pruning, climber cutting and other tending, protection measures against fire, pests and diseases, and thinning. In the case of the latter, incidental revenue (after deducting marketing costs) should be recorded so that a net thinning cost (or surplus) can be arrived at;

(*n*) the years in which any of the above costs are incurred must be recorded so that cost figures can be used in any method of economic analysis involving capitalization or discounting.

Another group of items whose costs may have to be capitalized covers those annual recurring operations whose intensity is more or less constant over the rotation. The annual cost is referred to under a variety of headings (annual administration, maintenance, annual charge, management, etc.). Departmental overheads might be included in this category. The range of costs reported, from around \$2 to \$10 per hectare, suggests that there are major differences in the accounting classifications. Moreover, it should be noted that the higher intensity of management in the establishment years and at the time of harvest felling can invalidate the assumption of a constant annual charge for management, etc. (Petrini, 1946).

As far as costs are concerned, one can only confirm Endsjø's findings about the limited comparability of the cost information presently available from different countries (Endsjø, 1967). Variation between the cost of a given item must be expected in view of the differences between regions, even within the tropical savanna zone, in the physical and economic factors influencing the quantity of inputs required and their unit prices. However, the width of the range that is evident for all cost items is so great that a substantial part of the variation must be an artefact of the recording and accounting practices. Before the cost experiences are of much use in the appraisal of tropical savanna plantation economics, they will need to be more comprehensive, more consistent and more rigorously specified, and, in order to achieve this, a comprehensive code of instructions and contents of universal application is badly needed. As it is, only broad analyses of extremely localized application can be made.

16. RETURNS

On the returns side there is much less information available and what exists is of limited value. The reasons for this are that the few plantations that have run through one or more rotations cover a relatively limited range of the ecological and economic conditions represented in the savanna. Very few, even of the small-scale trials, of which there are now many over a wide range of savanna conditions, have been established for long enough to give figures over a whole rotation. Furthermore, some of them are showing so much variability that the need for more trials is indicated in order to establish an acceptable level of reliability in the estimates. Thus, the form and quantity of the data currently available are of very limited use for the purposes of investment appraisal. They do, however, give some indication of the range of possibilities. The following rates of production have been recorded and can be compared with the production from the natural savanna vegetation which ranges from a negligible amount to 1-1.5 cubic metres per hectare per year.

TABLE 27. — TEAK YIELD IN THE DERIVED SAVANNA OF NORTHERN NIGERIA

Age	Poles		Sawtimber		Average dbh	
	Number/acre	*Number/hectare*	*Cubic feet/acre*	*Cubic metres/hectare*	*Inches*	*Centimetres*
6	230	568	—	—	3.5	8.9
10	230	568	—	—	5.5	14.0
15	90	222	—	—	8.0	20.3
20	50	124	—	—	10.0	25.4
25	10	25	210	14.7	12.5	31.8
30	5	12	370	25.9	14.0	35.6
40	—	—	640	44.8	18.0	45.7
50	—	—	3 200	223.9	—	—
Total	615	1 519	4 420	309.3	—	—

Teak

Yield calculations in Table 27 are based on Quality Class 1 of the Indian Yield Tables with adjustments with regard to Nigerian sample plot

FIGURE 28. Twelve-year-old *Tectona grandis* plantation during the dry season at Nimbia, Nigeria. Mean diameter, 18 centimetres; top height, 17 metres; basal area, 22 square metres/hectare.

(*Courtesy* P.J. Wood)

data and the heavier thinning regime proposed (Barrott, no date). Usual mean annual increment figures from the derived savanna are likely to be in the 7 to 11 cubic metres/hectare/annum range.

Gmelina arborea

Under the best savanna conditions this species is capable of very high production rates. On good sites in Malawi, where it attains a height of 16 metres in ten years, the mean annual increment at that age was 30 cubic metres/hectare per year. In Nigeria, assessments of production for pulpwood gave the following figures (Lamb, 1968):

TABLE 28. — YIELD OF *Gmelina arborea* IN NIGERIA

	Cubic feet/acre/year	Cubic metres/hectare/year
On poor sandy soils (age 12)	100	7
On good clay or laterite soils	250	18
On the most favourable savanna sites (age 10)	360	26

(Still higher yields up to 32 cubic metres/hectare/year for high-forest sites in Nigeria have been estimated.)

Azadirachta indica (neem)

Yields of firewood and poles in the Sudan zone on an eight-year rotation are between 28 and 170 cubic metres/hectare, indicating mean annual increment of 3.6 to 21.4 cubic metres/hectare/year. The majority of the plantations are in the lower third of this range (Gravsholt, Jackson and Ojo, 1967).

Eucalypts

The great mass of eucalypt planting is recent and few crops have been through a rotation. While there is a mass of data on early height growth in trials and increment plots, much of which indicates high rates of future production, there is little data on volume production.

Both *Eucalyptus camaldulensis* and *E. tereticornis* have been extensively planted and, provided suitable provenances have been used, high yields of fuel and poles (more than double that of *Azadiracta indica* on similar sites) may be expected. And with selection and hybridization, still further improvements may be expected. Groulez, 1967b, reports that the strain known as *Eucalyptus* sp. 12 ABL from Madagascar, when grown in Congo, has produced yields of 48 cubic metres/hectare on poor sites at Loandjili and 80 to 88 cubic metres/hectare on very good sites at Loudima at an age of only four years, indicating mean annual increments of 12 cubic metres/hectare/year at Loandjili and 20 to 22 cubic metres/hectare/year at Loudima. At this age, of course, the mean annual increments would be increasing rapidly.

The climate at Loudima is, however, close to a humid tropical climate, where better species of eucalypts, such as *E. "grandis,"* would normally be preferred. *E. camaldulensis* has a reputation for bad form and the Zanzibar *Eucalyptus "C,"* probably a provenance of *E. tereticornis*, is likely to prove straighter.

Where *Eucalyptus "grandis"* plantations are now reaching maturity, reasonably reliable estimates of yield are available. The following yield table is based on recent measurements in the Chati-Lamba plantations in Zambia (Sandwell, 1971).

TABLE 29. — BASIC YIELD DATA FOR *Eucalyptus "grandis"*

Cut	Age	Mean height		Mean dbh		Volume (ub)	
		Feet	*Metres*	*In.*	*Centimetres*	*Cubic feet/acre*	*Cubic metres/hectare*
First thinning	3	60	18.3	6.4	16.3	540	37.8
Second thinning	5	75	22.9	8.8	22.4	865	60.5
Third thinning	6	82	25.0	10.2	25.9	640	44.8
Final cut	8	87	26.5	11.6	29.5	1 075	75.2
Total						3 120	218.3
Mean annual increment						390	27.3

There are many *Eucalyptus* species suitable to the moister zones that have advantages of high production combined with good form and timber quality. The possibilities of improving both rates of production and bole form and timber quality have hardly begun to be realized.

Pinus caribaea

This is, so far, the most promising coniferous species for low-level planting in the tropics and there are many trial and increment plots in a number of countries. Nearly all, however, are too young to give indications of the volume yields that may be expected.

The most informative data come from Tanzania, where this species has been planted in more than 80 trial and tree-increment plots since 1953 and where there are now (1971) more than 2 750 hectares of plantations, chiefly in the coastal region at 80 to 700 metres' elevation, Lake Victoria region, 1 150 metres to 1 250 metres, and on Ukaguru mountain, 1 000 metres to 1 150 metres. The area of the trial plots varied from 0.04 to 0.26 hectares and it is not known whether the plots had adequate surrounds, without which edge effects may have inflated the volume figures. Most of the plots were remeasured in 1970 and the results reported by Borota, 1971. Excluding two very poor plots at Kitule on obviously unsuitable sites, the mean annual increments of plots between 10 and 15.7 years of age (16 plots) ranged from 16.7 cubic metres/hectare/year to 49.2 cubic metres/hectare/year, the mean being 28.9 cubic metres/hectare/year. In the better plots the mean top height increment varied between 1.5 and 2.0 metres per year and the mean diameter increment from 2.0 to 2.5 centimetres. These are fantastically high rates of growth and, even allowing for the possibility of edge effects in the plots, they must be regarded as highly satisfactory. The rainfall varied between 800 and 1 800 millimetres. Neither the kind of soil nor the provenance or variety of the pine are mentioned, but it is known that most of the early trials were of seed of var. *hondurensis* from the Mountain Pine Ridge of British Honduras.

Comparisons of rates of growth in plantations in other savanna countries are difficult to make, either because no volume measurements have yet been made or because the plantations are too young. On the basis of early height growth in plantations in Rhodesia in a rainfall over 1 000 millimetres and at elevations below 1 200 metres, the trees are growing at broadly similar rates to Tanzania, but the oldest plantations are only 8.4 years old (Barrett and Mullin, 1968). The growth rate falls off very rapidly at higher elevations.

In Zambia, trials of this species were at high elevations (1 160 to 1 370 metres) and it grew less well than *Pinus kesiya* (Philippines strain), which is now the preferred species for large-scale plantations. It is, however, still considered a second or third choice to *P. kesiya* on some sites.

FIGURE 29. Six-year-old plantation of *Pinus caribaea* on Jos Plateau, Nigeria.
(*Courtesy* J.K. Jackson)

In Nigeria, extensive trials and provenance experiments at lower elevations show great promise, the var. *hondurensis* being superior to all other strains tested. The following growth figures are available for this variety from Nigeria.

TABLE 30. — GROWTH FIGURES FOR *Pinus caribaea* [1]

Site	Age	Top height	Total volume/ hectare	Seed origin
		Metres	*Cubic metres*	
Jos Plateau	11	17.1	261	British Honduras
Afaka	6	7.0-8.5	60-82	British Honduras

[1] Allan, 1973b.

On very poor savanna in Congo, at Pointe-Noire, Martin, 1970, gives volume figures for young plantations on a permeable sandy soil

that had been impoverished by many years of cassava cultivation. The rainfall was about 1 470 millimetres with a uniform mean monthly humidity throughout the year. Mean annual increments at nine years and two months old ranged from 7.4 to 10.3 cubic metres/hectare/year and were rapidly increasing. Approximately double these rates were obtained at Loudima on good soils in a humid tropical climate.

The provenance and variety of *P. caribaea* used is important and there is little doubt on present evidence that, for those countries lying between latitudes 5 and 10°N, the most tropical provenance, notably *P. caribaea* var. *hondurensis*, is the most suitable for planting at elevations below 1 000 metres.

Pinus oocarpa

This species has shown as good, and sometimes superior, growth to *P. caribaea* var. *hondurensis* in some northern Nigeria trials, but more research will be needed before it can be established whether it is likely to compete with it for large-scale plantation work.

The following growth figures are available from Nigeria.

TABLE 31. — YIELD FIGURES FOR *Pinus oocarpa* [1]

Site	Age	Top height	Total volume/hectare	Seed origin
		Metres	*Cubic metres*	
Jos Plateau [2]	18	22.3	232	Honduras
Afaka	6	8.2	45	Mexico
Afaka	6	9.8	73	British Honduras

[1] Allan, 1973b.
[2] The Jos Plateau plantation was spaced at 5 × 5 metres (18 × 18 feet). A higher volume could be expected at closer spacing.

Pinus oocarpa var. *ochoterenai* and one provenance of *P. oocarpa* var. *oocarpa* are doing very well in Zambia up to age nine and eleven years respectively, the latter of excellent form and with a growth rate comparable to *P. kesiya* (Greenwood, 1969).

Pinus kesiya

Savory, 1962, records a mean annual increment of 32.2 cubic metres/hectare/year for the Philippines strain of this species at an age of 20 years, when growing at an elevation of 1 160 metres under a rainfall of 1 140 to 1 270 millimetres, with a six to seven months dry season. This was on the northern plateau in Zambia, on a deep sandy soil. The strain from Assam, India, grew more slowly, having a mean annual increment of only 24.5 cubic metres/hectare/year in the same trial. The form of the Philippines strain was also much superior.

FIGURE 30 Stand of *Pinus kesiya*, thirteen years old, at Ndola, Zambia.
(*Courtesy* Forest Department, Zambia)

The above yields are from single plots on excellent sites and may be somewhat higher than can be expected from the usual industrial plantation. A recent study (Sandwell, 1971) based on revised guide curves and field measurements in plantations near Ndola, Zambia, suggests the following basic yield table.

TABLE 32. — BASIC YIELD DATA FOR *Pinus kesiya*

Cut	Age	Mean height		Mean dbh (ob)		Volume (ub)	
		Feet	*Metres*	*In.*	*Centimetres*	*Cubic feet/acre*	*Cubic metres/hectare*
First thinning	6	31	9.4	4.9	12.4	127	8.9
Second thinning	8	45	13.7	7.5	19.0	352	24.6
Third thinning	12	56	17.1	9.3	23.6	559	39.1
Fourth thinning	21	84	25.6	14.5	36.8	1 294	90.5
Final cut	30	102	31.1	19.6	49.8	5 464	382.3
Total						7 796	545.4
Mean annual increment						260	18.2

Summarizing briefly the yield prospects from savanna plantations:

(*a*) In all climatic zones it is possible to grow plantations of exotics that will produce wood at a much higher rate than the natural forest.

(*b*) In the driest type (Climatic type 2, subdesert) it is unlikely that any plantations will produce high enough yields to make them economic from the financial angle, though occasionally planting may be worthwhile to relieve local shortages of fuel. Exceptions are when irrigation is available or where groundwater is present, when useful yields of fuel and small poles may be obtainable on short rotations.

(*c*) In Climatic type 3 (dry tropical) there is a limited range of species which will give reasonable yields of fuel and small poles and may be economic in plantations, notably several species of eucalypts (*E. camaldulensis* and its hybrids, *E. microtheca* for the drier sites and *E. tereticornis* on the less arid sites). Research into provenance and hybridization will undoubtedly improve the range of suitable varieties and their rates of production.

(*d*) In Climatic type 4 (semihumid tropical) there are a number of species of eucalypts and their hybrids that may produce high yields (15 cubic metres/hectare/year and upward) giving, in addition to fuel and small poles, larger telegraph and transmission poles, pulpwood and some saw timber. Conifers, notably *Pinus caribaea* var. *hondurensis* at low elevations and *P. kesiya* at higher elevations show promise of high yields of long-fibred pulpwood and of valuable general purpose softwood timber.

(*e*) In Climatic type 5 (humid tropical, including derived savanna), in addition to most of the species suitable for Climatic type 4 which will grow still faster, many desirable timber-producing trees can be grown, e.g. teak, *Gmelina*, etc. Yields can be very high. *Gmelina* on the best sites may exceed 25 to 30 cubic metres/hectare/year and the pines may occasionally exceed these rates, though the average for the sites available in this climatic type will be much less. Nevertheless, the potential is there for plantations that will produce sufficient quantities of raw material of good quality to support a range of wood-using industries.

To sum up, the above figures of production in terms of mean annual increment indicate that, given the right species and provenance, together with careful site selection and appropriate silvicultural techniques, there are large areas of the savanna from which high production can be obtained. Admittedly the areas from which the very high increments over, say, 20 cubic metres/hectare/year can be expected, are limited, but there are still vast areas from which yields of between 10 and 18 cubic metres/hectare/year can be realized, thanks mainly to the introduction of fast growing species of eucalypts. These high returns could go a long way toward meeting the demand for fuelwood and poles throughout the savanna region and in some cases could support wood-using industries.

The other element in returns from the plantations, namely prices, is almost impossible to quantify in any meaningful way that has general applicability. Every situation in every country is different. But when a product such as firewood or small poles cannot be supplied more cheaply from other sources, such as imports or by substitution, and is needed badly enough, a price will emerge based on the cost of production.

17. ECONOMIC PROSPECTS OF SAVANNA PLANTATIONS

In view of the absence of reliable data for the financial returns from plantations, it is doubtful whether anything useful can be said at the present time about the economic prospects of plantation schemes in the savanna region. Some will, by comparison with European experience, be manifestly very profitable. Others will be more doubtful and some clearly will, from a purely financial angle, make a loss.

Some recent calculations of the cost of growing wood in savanna plantations (FAO, 1969a) range from \$1.60 to \$12.20 per cubic metre for the best and worst likely situations, but these inevitably contain so many assumptions (including an interest rate of 7 percent for compounding costs) that they are highly speculative. Nevertheless, they provide a bracket within which the true answer probably lies.

To speculate still further, if the cost of production from a particular plantation project worked out at, say, \$4 per cubic metre, firewood and poles selling at \$4.50 per cubic metre would make a useful direct profit. On the other hand, if the price obtainable were only \$2 per cubic metre, the plantations could not support themselves out of the direct financial returns and could only be justified if there were additional indirect benefits outside the financial calculation.

For plantation projects to be "worthwhile," which is another way of saying "economic," the overall benefits (including both direct and indirect benefits), must be greater than the costs. This apparently simple statement requires a great deal of qualification and definition before an adequate comparison between costs and benefits can be made. For instance, it must be decided what benefits are to be credited, what beneficiaries are to be included, what costs are to be debited and so on. Because a straightforward accounting (if such accounting is ever straightforward!) of financial costs and returns shows a loss, it does not necessarily mean that the plantations are not worthwhile.

Indirect benefits often have to be taken into account, such as rural employment and other social benefits, community stabilization, import replacement, etc. The problem of how to evaluate indirect elements is still a long way from being satisfactorily solved. At present the possibilities are still quite high for manipulating the values attached to indirect benefits and costs so as to produce almost any desired result!

It is possible to regard the difference between the cost of a plantation and the financial return as a measure of the "opportunity cost" of the indirect benefits accruing.

In conclusion, the following points may be made regarding the economic aspects of savanna plantations.

1. Currently available data on the costs and yields from tropical savanna plantations are far too sketchy and inconsistent for anything but strictly local application or the broadest of extrapolations.
2. There is a glaring need for the collection and dissemination of more comprehensive and carefully specified data according to a standardized format.
3. Continued research on plantations in tropical savannas is clearly justified, provided a substantial part of the effort is directed toward reducing costs and increasing growth rates.
4. A great deal of socioeconomic and biological research is needed before the evaluation of indirect benefits and costs can proceed beyond fairly broad estimates in terms of opportunity costs.
5. Plantations in tropical savannas, where low costs, high yields and reasonable prices can

be expected, stand a good chance of being justifiable as financial investments alone.

6. A great deal of caution needs to be exercised with proposals involving difficult conditions leading to high costs, low yields or low prices.

7. Alternative methods of meeting social objectives need to be assessed from the points of view of economic, social and political feasibility, when it is expected that the justification for a project must rely heavily on the indirect benefits.

18. SPECIAL CASES

Irrigated plantations

The economics of the Gezira irrigated plantations in Sudan are being investigated and the following information is summarized from the data so far collected.

The cost of establishing 1 feddan of *Eucalyptus microtheca* plantation is £S25, which is equivalent (at conversion rate of $2.80 to £S1 and 0.42 hectares to 1 feddan) to $166 per hectare. This includes ridging, cost of plants, beating up, weeding, including a weeding in the second year, and supervision. The average rotation is eight years. Felling and conversion costs are about $134 per hectare. The produce sells, at controlled prices for the benefit of the tenants, for $400 per hectare. The free market price would be higher. The average yield from *E. microtheca* is 60 solid cubic metres per hectare at rotation age. The costs of initial establishment must be spread over the second and possibly more rotations which makes a better financial rotation than appears at first sight. Also, a higher yielding species, costing no more than *E. microtheca* to establish, would make a considerable improvement in the net return. Further, it is highly probable that the second rotation (first coppice rotation) will be reduced to six or seven years at the most.

There are also indirect savings in providing wood needs on the spot. If wood has to be brought from long distances, it has to come in lorries, using foreign currency in the form of imported petrol and spare parts; or by rail, using wagons that may be badly needed for some other work. The cost of such imported wood is consequently higher, so that the tenant has to pay more of his income for his basic necessities, lowering his standard of living in the process (Booth, 1966).

Acacia senegal plantations

The yield from the natural *Acacia seyal* savanna in Sudan is 12 to 17 stacked cubic metres per hectare. The net financial return is between $10 and $13 per hectare. Conversion of this type of savanna to *Acacia senegal* plantations costs between $20 and $33 per hectare for removal of trees and stumps, with a return from the charcoal and firewood produced; establishment of the plantation by mechanical means costs $20 per hectare. The rotation is 15 to 20 years and no plantation has been established long enough for the costs of supervision to be worked out. The financial return from gum collection had, at 1964/65 prices, a gross value of $53 per hectare, starting from the fifth to seventh year after establishment and thereafter annually. The net value of the gum, if given to the local people by the usual practice of half the crop to the tapper and half to the owner, would be $26.50 per hectare. The final yield of wood is expected to be 120 to 190 stacked cubic metres/hectare with a net value of $100 to $160/hectare. The costs of establishment must be spread over the succeeding coppice rotations; the number of rotations possible is not known, but evidence from a stump dug out in Kordofan showed four previous coppice scars (Booth, 1966).

APPENDIXES

VEGETATION TYPES OF THE SAVANNA

Within the main vegetation formations of woodland, savanna and steppe, described in Chapter 1, a number of types are shown separately on the Vegetation map (see maps, centre inset). Notes on these follow. References are to the type numbers shown on the map and the notes are taken from the *Explanatory notes* accompanying the Vegetation map published by the Association pour l'étude taxonomique de la flore d'Afrique tropicale in 1959.

Type 15. Forest-savanna mosaic

" In this mosaic, patches of moist forest (not confined to stream sides) are surrounded by savanna of tall grasses. Moist forest (evergreen or partially evergreen) occurs along streams and on other moist ground both in this type and also in all the relatively moist woodland and savanna types [Nos. 22-25], but only in the areas mapped as Forest-Savanna Mosaic are the moist forest patches found also on hills and plateau sites.

" The flora of the forest patches is relatively rich and is more or less the same as in the adjoining areas of Moist Forest [type 14]. By contrast the savanna is usually poor floristically: *Pennisetum purpureum*, *Loudetia arundinacea*, *Imperata cylindrica*, or some other grass, may assume almost complete dominance in the herb layer. This savanna is normally burnt each year and, since it burns fiercely, only fire-tolerant trees and shrubs can survive. Among the latter, *Hymenocardia acida* is especially characteristic. In areas near the savanna woodland regions [types 22-25] the savanna [of type 15] usually has a number of relatively fire-tolerant woodland trees and shrubs; *Lophira lanceolata* and *Daniellia oliveri* are good examples north of the Equator. Patches of savanna within the Moist Forest regions tend to be poor in woody species.

" If the fires are excluded for several years this kind of savanna may be invaded by moist-forest species. In much of the country mapped as Forest-Savanna Mosaic the climate is not more arid than parts of the Moist Forest regions and it is generally agreed that the savanna in the mosaic has been derived by degradation from Moist Forest."

Type 16. Coastal forest-savanna mosaic

" Physiognomically, this resembles the preceding type, except that the forest patches and the savanna grasses tend to be less tall. Rainfall in these coastal areas is lower than in the Moist Forest regions, but the more evenly distributed rain and higher relative humidity seem to account for the vegetation being different from inland areas of comparable annual rainfall which are occupied by relatively dry types of woodland, savanna, and steppe.

" The ' Coastal Scrub and Grassland Zone ' of Ghana (Taylor, 1952) comes into this category; it occupies a zone, nowhere more than 25 km. wide, between the sea coast and the Moist Forest ...., but contain also a few special species and a number of plants characteristic of relatively dry inland areas. Woodland with such species as *Anogeissus leiocarpus* is invading the Coastal Savanna from the north-east.

" By contrast, the zone of Coastal Forest-Savanna Mosaic in eastern Africa is relatively more humid and hot than the hinterland of types [24 and 31]. The patches of forest and evergreen scrub are separated by at least 1 000 km. from the main block of Moist Forest [type 14] and it is not surprising to find that they are very different floristically. The surrounding savanna often has abundant acacias and other species characteristic of types [26 and 31]; *Adansonia digitata* is a characteristic tree in this coastal savanna."

Types 22, 23, 24, 25, 26, 27, 28. Woodlands, savannas (and steppes)

" A number of rather diverse vegetation types are included here. They occupy extensive tracts with moderate rainfall and severe dry seasons. Although the climax vegetation is generally thought to be closed woodland with little grass, practically the whole area is covered by grasses ranging in height from about 80 cm. to 3 or 4 m. Grass fires are liable to occur every dry season and most of the trees are fire-tolerant to a greater or less extent.

" Over wide areas of relatively sparsely populated country the trees attain 7-25 m. in height and form a light canopy over grass, but with very little shrubby undergrowth; in certain rather moister areas, and locally where there is protection from fire, the shrubby undergrowth may be better developed. The density of tree-cover varies considerably according to edaphic conditions and human interference. All stages from woodland to grass savanna (or even grass steppe) are commonly found within a few hectares.

" Areas of steppe are of very limited extent in types [22 and 23], and local in [24]; they are a very characteristic feature of type [25]; they occur sporadically in types [26, 27 and 28]."

Type 22. Undifferentiated — relatively moist types

" One of the great features of the woodlands of tropical Africa is the dominance, over wide areas, of the genera *Isoberlinia*, *Brachystegia* and *Julbernardia*. Woodlands of relatively moist type, in which these three genera are absent or rare, are included in type [22] on the map. There is inevitably a good deal of diversity in this ' undifferentiated ' group of types. Most of them have in common, however, a very dense growth of tall grass and fires are usually more severe than in types [23-25].

" In the northern part of tropical Africa there is a long belt of type [22] between the Forest-Savanna Mosaic [type 15] and the Woodland with abundant *Isoberlinia doka* [type 23]; *Daniellia oliveri* and *Lophira lanceolata* are widespread in this belt.

" In many parts of eastern and southern tropical Africa species of *Combretum* are abundant; *Piliostigma thonningii* and *Annona* spp. are also characteristic."

Type 23. Northern areas: with abundant Isoberlinia doka and I. dalzielii

" Although woodland of *Isoberlinia doka* and *I. dalzielii*, often associated with clumps of *Uapaca togoensis*, are characteristic and often abundant in this type, the configuration of the ground is such that they are seldom continuous for more than a few kilometres.

" These species are often replaced on eroded slopes by *Monotes kerstingii* and on poorly drained clay depressions by *Terminalia macroptera* and *T. laxiflora*. Tall grass savanna, sometimes with *Borassus* palms, occurs in wide valleys and strips of evergreen forest fringe the streams."

Type 24. Southeastern areas: with abundant Brachystegia and Julbernardia

" In these woodlands, commonly known by the vernacular name of ' myombo,' several species of *Brachystegia*, notably *B. spiciformis* and *B. boehmii*, and *Julbernardia globiflora* and *J. paniculata* are dominant over extensive areas. *Brachystegia* and *Julbernardia* seldom occupy the relatively low-lying ground of the river valleys which may be treeless. Woodland and savanna dominated by other genera (e.g. *Monotes*, *Terminalia*, *Combretum*, and *Acacia*) often occupy distinct zones between the ' myombo ' woodland and the open valley grasslands. Strips and patches of more or less evergreen moist forest occur in especially moist but well-drained sites, notably by streams. A few rather large patches of Moist Forest surrounded by woodland have been shown on the map in Katanga."

Type 25. Southwestern areas (principally on Kalahari Sand)

" The ' myombo ' woodland in these areas is similar to that of [type 24], but includes a number of distinctive species such as *Marquesia acuminata*, *Cryptosepalum pseudotaxus*, and *Guibour-*

tia coleosperma. Communities dominated by one or the other of the latter two species replace the true *Brachystegia-Julbernardia* ' myombo ' in certain areas.

The woodland of the moist northern areas around latitude 7°S. is considerably more luxuriant and richer in species than that of the drier southern areas around 17°S. In these drier areas there is a certain amount of interdigitation with the *Baikiaea* Dry Deciduous Forests.

" A distinctive feature of this type is the occurrence of treeless steppe [type 30] on the plateaux."

Type 26. Undifferentiated relatively dry types

" A considerable range of floristic types is included here. Climatically, most of them come between the moister types of Woodlands [types 22-25] and the Wooded Steppe with abundant *Acacia* and *Commiphora* [type 31].

" In eastern tropical Africa [type 26] and in south tropical Africa [types 26 and 28] are particularly well developed in the big river valleys and even occupy many small valleys within the areas of [types 22-25].

" The savanna types are in general more extensive than the steppe, and although the acacias are often frequent, there are many broad-leaved trees such as species of *Combretum* and *Terminalia*; *Adansonia digitata* and *Sclerocarya* are particularly abundant in this type.

" Also included here are alluvial savannas of tall grass with certain species of *Acacia*, notably *A. polyacantha* subsp. *campylacantha* and *A. sieberiana*. These communities of *Acacia* with tall grass are very different ecologically from the steppe communities [e.g. type 31] in which other species of *Acacia* are dominant."

Type 27. Ethiopian types

" These woodlands are a heterogeneous assemblage of low deciduous trees and shrubs with an undergrowth of shrublets and perennial grasses. *Boswellia papyrifera* and species of Combretaceae are characteristic.

" The woodlands occupy stony ground and are interrupted by patches of savanna; they merge into the *Oxytenanthera* bamboo thickets."

Type 28. With abundant Colophospermum mopane

" Since the dominant tree *Colophospermum mopane* is tolerant of ill-drained soils this distinctive type is associated with large river valleys; it occurs only in southern Africa. At its best ' mopane ' forms deciduous woodlands 15 m. or more high, with little or no understorey: there are, however, many areas of low scrubby ' mopane,' especially in areas liable to frost. Associated types include valley grasslands and mixed woodlands, savannas and steppes, with such trees as *Adansonia digitata*, *Kirkia acuminata*, and species of *Acacia*, *Combretum*, and *Terminalia*. The climate associated with this type is hotter and drier than in the adjoining woodlands [types 24 and 25]."

Type 29. Madagascar grass savanna and grass steppe

" The central part of Madagascar is mostly occupied by grasslands (both savanna and steppe types) with scattered shrubs but very few trees. A few remnants of the original forest vegetation [type 18] are found in places which have been protected from fire."

Type 30. Grass steppe on Kalahari Sand

" Many of the grasses in this vegetation have rolled or narrow, mainly basal, leaves. Perennial plants with stout woody underground parts from which arise each year woody or herbaceous aerial shoots bearing flowers and fruits are a characteristic feature of these steppes, which occur on the plateaux in woodland regions on Kalahari Sand. They have a distinctive flora."

Type 31. Wooded steppe with abundant Acacia and Commiphora

" Vegetation classified under this heading covers large tracts between the desert and subdesert types on the one side and moister woodland types on the other.

" The appearance of the vegetation depends on the relative abundance of the trees and shrubs. In some places the trees, mostly of species ot

Acacia and *Commiphora*, form open or closed woodland or thickets; in other places the trees are widely scattered. Most of the trees are deciduous, fine-leaved and thorny.

"The grasses, usually less than 1 m. high, include such species as *Chrysopogon aucheri*, *Aristida stipoides*, *Cenchrus ciliaris*, *Sporobolus variegatus* and *Schoenfeldia gracilis*; in S. Africa and in some lower montane areas *Themeda triandra* is abundant.

"In the wider river valleys there is much *Acacia* savanna with tall grasses, (e.g. *Beckeropsis* and *Hyparrhenia*)."

Type 32. Grass steppe with thicket clumps: western Uganda type

"The thicket clumps contain shrubby species of such genera as *Rhus*, *Grewia*, *Carissa* and *Capparis* as well as candelabra-euphorbias. The clumps are surrounded by short grassland which is being invaded in some areas by *Acacia hockii*.

"Similar vegetation also occurs in [types 26, 28 and 31]: the W. Uganda area has, however, been mapped and is large enough to show on the scale of 1 : 10 000 000."

Type 33. Grass steppe: Luanda type

"This area, mainly of grassland dominated by *Setaria welwitschii*, occurs in Angola on coastal plains from Luanda southward to the River Eval."

Types 35, 36 and 37. Subdesert steppe

"... The areas mapped as Subdesert Steppe usually merge imperceptibly into Wooded [tree or shrub] Steppe [type 31] on one side and into Desert [type 39] on the other; on both sides, there is interdigitation with the adjoining types. Low perennial plants are widely spaced; annuals, including grasses (e.g. *Aristida* spp.), flourish for a few weeks after rain."

Type 37. Tropical types of subdesert steppe

"Species of *Acacia* and *Commiphora* occur here, as in [type 31], but are of low stature and widely spaced; *Salvadora* and *Leptadenia pyrotechnica* are also characteristic."

WATER BALANCE FOR SELECTED STATIONS IN THE SAVANNA

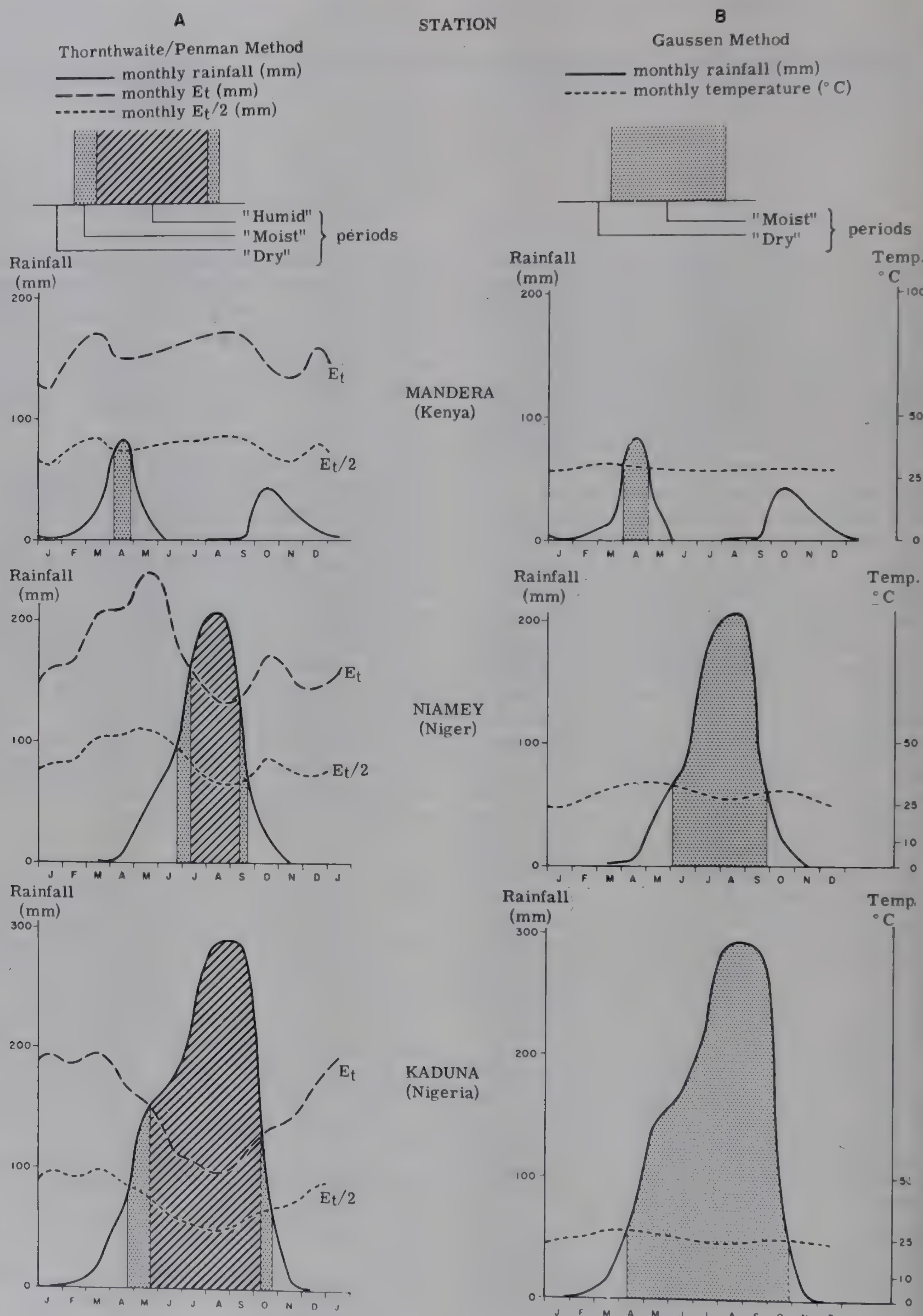
An idea of the variation in water balance which may be experienced throughout the year within the broad region of the savanna may be obtained from diagrams of estimated water loss from evapotranspiration and water gain from rainfall. Various empirical models have been used for this purpose, and for temperate climates those of Thornthwaite, 1948, Penman, 1948, and Gaussen, 1954, among others, have been the most useful. Of these, Penman's method is the most sophisticated. In this, the potential evapotranspiration (E_t), which may be defined as the water loss from evaporation and transpiration that would take place over a given period of time if a surplus of moisture were available in the soil all the time, is determined from a number of meteorological parameters which together enable the net solar energy available for causing evapotranspiration to be estimated. Thus *potential* evapotranspiration (E_t) estimates the evaporative demand of the atmosphere over a given period. When E_t and rainfall are used in conjunction, they should constitute a more reliable basis for comparison of climates within the savanna than rainfall alone. On the other hand, it should be noted that E_t cannot be used directly in savanna climates to estimate *actual* evapotranspiration (E_a), since the latter is greatly influenced by other factors, such as the capacity of the soil to store moisture and the response of the plant to the environment through regulating its transpiration rate.

E_a falls below E_t as soon as the surface of the soil becomes dry or when the water in the rooting layer becomes in short supply, causing the plant to regulate its transpiration by stomatal closure. In temperate climates, the difference between E_t and E_a is much less than in the tropics so that the model based on E_t gives fairly realistic estimates of the actual water balance throughout the year and provides a useful integrated picture of the climate from a plant growth point of view. When this method is applied to savanna conditions in the tropics the differences between E_t and E_a are very much greater and more variable. Furthermore, the formula, in its usual form, is only applicable to surfaces covered with continuous uniform vegetation. Irregular stocking, such as is typically found in savannas will, theoretically, absorb more solar energy and have a higher E_t.

Penman's formula provides the best model available at the present time for computing E_t and hence obtaining a comparative picture of different climatic regimes from the point of view of water balance throughout the year. More research is required to quantify the effects of other factors such as run-off, soil moisture storage and plant-water relations, in order to obtain a realistic estimate of actual evapotranspiration and actual water balance applicable to irregular vegetation in tropical climates.

As an example of the application of Penman's method to savanna conditions, six stations have been selected, three in the northern and three in the southern hemisphere as follows:

Station	Country	Latitude	Longitude	Altitude	Annual rainfall	Total annual evapotranspiration (E_t)
				Metres	*Millimetres*	
Niamey	Niger	13°30'N	2°07'E	200	638	2 057
Kaduna	Nigeria	10°35'N	7°26'E	644	1 298	1 793
Mandera	Kenya	3°57'N	41°52'E	331	218	1 844
Dodoma	Tanzania	6°10'S	35°46'E	1 120	574	1 283
Lubumbashi	Zaire	11°39'S	27°28'E	1 290	1 229	1 181
Maun	Botswana	19°59'S	23°25'E	942	471	1 399


A
STATION
B
Thornthwaite/Penman Method
monthly rainfall (mm)
monthly Et (mm)
monthly Et/2 (mm)
"Humid"
"Moist"
"Dry"
periods
Gaussen Method
monthly rainfall (mm)
monthly temperature (°C)
"Moist"
"Dry"
periods
Rainfall (mm)
Temp. °C
MANDERA (Kenya)
NIAMEY (Niger)
KADUNA (Nigeria)
Et
Et/2
J F M A M J J A S O N D

For each station, two diagrams are shown. Both series of diagrams show the months along the abscissa, starting with the month following the winter solstice on the left (January in the northern, July in the southern hemisphere).

In the first series (series A) mean monthly rainfall and mean monthly potential evapotranspiration (E_t), calculated by the Penman method but assuming a reflection coefficient of 0.25 for continuous vegetation cover, are plotted to the same scale in millimetres. The two series of points are joined to produce two curves extending over the year, one for rainfall, the other for potential evapotranspiration. The shape of the curves and their relationship to each other indicate the season, and length and relative intensity of the wet and dry seasons.

The period or periods during which the amount of rainfall in successive months exceeds the corresponding potential evapotranspiration (E_t) constitutes the " Humid " period or periods. A convention which has been used by some workers (Brown and Cochemé, 1969, Cochemé and Franquin, 1967) is to calculate, in addition, the figure corresponding to half the monthly potential evapotranspiration ($E_t/2$). With this convention, the period during which monthly rainfall exceeds $E_t/2$ is designated as the " Moist " period. The " Moist " period includes within it the " Humid " period if any. In the first series of diagrams reproduced here the curve for $E_t/2$ is shown, as well as that for E_t.

In a month in which rainfall exceeds E_t, the surplus water is available for recharging the moisture reserves in the soil until field capacity is reached in the surface layers of the soil. Thereafter excess rainfall is lost through runoff or deep percolation.

When E_t exceeds rainfall, water reserves in the soil will be used up. The rate of loss will be equal to E_t to start with, but as soon as the soil surface becomes dry or the availability of moisture in the soil falls off to a level that causes moisture stress in the vegetation the actual rate of loss of water (E_a) will slow down and fall below the value of E_t. These conditions, where E_a is less than E_t, prevail over a large part of the year under dry tropical savanna conditions, and when E_t is highest, E_a is around its minimum value.

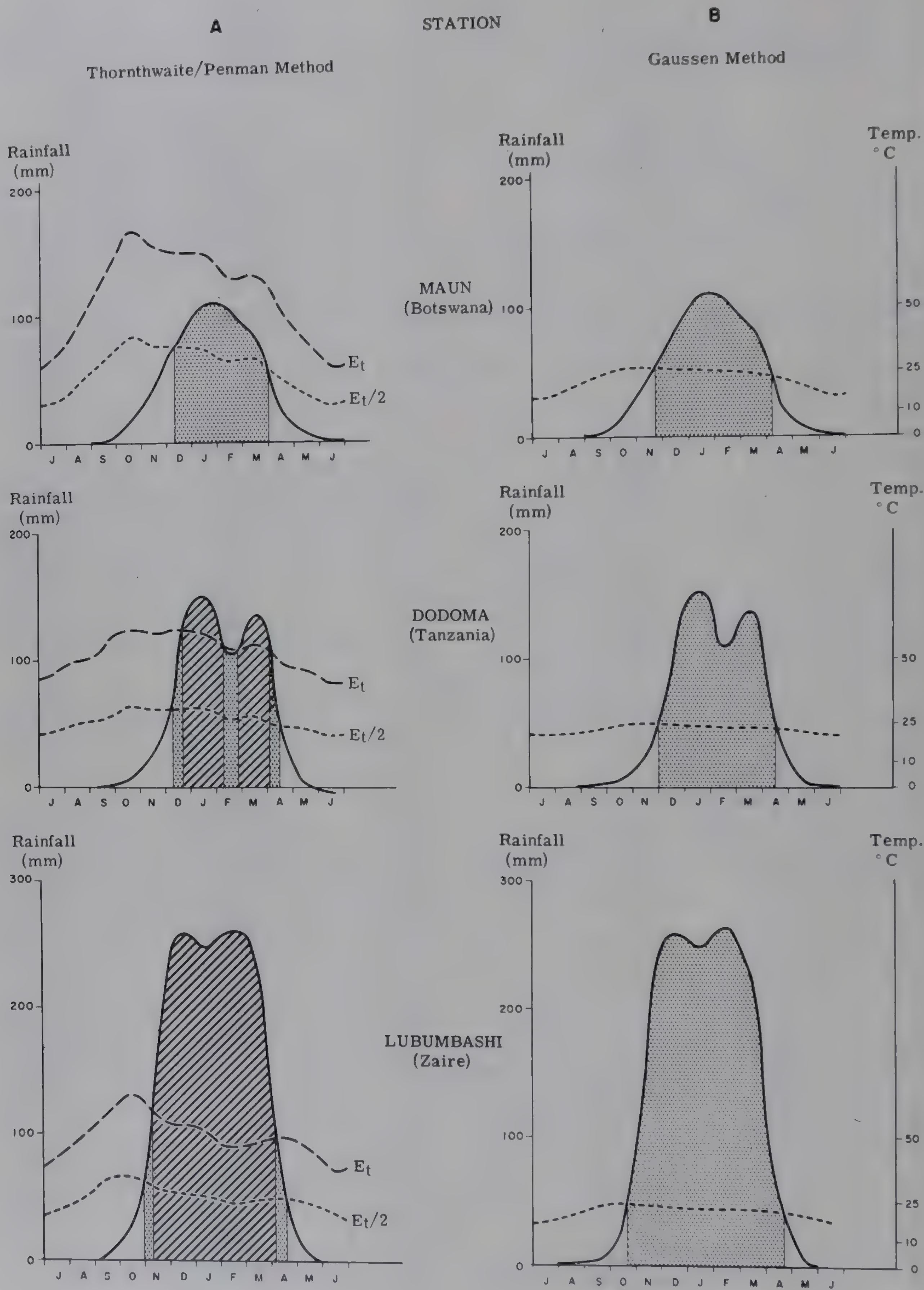
A correct curve of E_a would follow E_t during the " Humid " and part of the " Moist " periods of the year, but would fall well below it during the dry periods. In this way the net amount of water received at the site (i.e. the rainfall minus losses from run-off and deep percolation) should exactly equal the actual evapotranspiration loss over the year, since, from year to year, there is assumed to be no consistent loss or gain of soil moisture over long periods.

The Penman method of representing water balance is (with suitable qualification of its interpretation as mentioned above) thought to provide the best picture available at present of the relative " dryness " and " moistness " of a site, but the determination of E_t needs a number of fairly sophisticated meteorological measurements. In many parts of the savanna, these are not available and a simpler method of comparing the moisture regimes of different sites, based on readily available measurements, is needed.

The second series (series B) of diagrams in this appendix illustrates the diagrammatic method of Gaussen which depends on rainfall and temperature measurements only (Gaussen, 1954, Unesco/FAO, 1963). It is inevitably cruder and more empirical than that of Penman, but it has been used with some success in the Mediterranean region. The method of presentation is as follows:

The months are represented along the abscissa as before. Mean monthly rainfall in millimetres is plotted to the same scale as in the first series of diagrams. In addition, mean monthly temperature in °C is plotted at a scale of 1°C = 2 millimetres of rainfall. The two series of points are joined to produce two curves, one for rainfall, the other for temperature. The part of the year when the temperature curve is above the rainfall curve (i.e. rainfall in millimetres is less than twice temperature in °C) is considered to be the dry season and the relationship of the two curves indicates its duration and intensity.

Comparison of the two series of diagrams shows that there is a fairly close similarity between the moist season as indicated by the $E_t/2$ curve in the first series of diagrams and that indicated by the simple temperature curve in the second series. The latter method offers useful possibilities where only simple rainfall and temperature data are available. A comprehensive series of diagrams of this kind are available in the *Klimadiagramm-Weltatlas* (Walter and Lieth, 1967) which includes many African stations.


A
STATION
B
Thornthwaite/Penman Method
Gaussen Method
Rainfall (mm)
Temp. °C
MAUN (Botswana)
DODOMA (Tanzania)
LUBUMBASHI (Zaire)
E_t
$E_t/2$
J A S O N D J F M A M J
0
10
25
50
100
200
300

MAIN SOIL TYPES IN THE SAVANNA

The factors which are generally held to affect soil development are climate, vegetation, geology, topography and time (Jacks, 1954). In young soils, geology is usually the dominant factor in determining soil characteristics, in ancient soils it is climate. Much of the savanna overlies ancient rock such as the Basement Complex, while in the northern hemisphere in western and central Africa there is a steady trend for total rainfall, mean annual humidity and length of the wet season to increase from the Sahara to the equator. In these conditions, the succession of climatic and vegetation types from north to south are broadly paralleled by the succession of soil types. To oversimplify, it may be said that the brown soils (type 12) are most characteristic of the semidesert climate and the driest parts of the dry tropical climate, where they are associated with subdesert steppe and wooded steppe vegetation, the ferruginous tropical soils (types 15, 16) are most characteristic of the wetter parts of the dry tropical climate, where they are associated with wooded savanna or wooded steppe vegetation, and an association of ferruginous tropical and ferralitic soils (types 16 and 20) is most characteristic of the semihumid tropical climate and savanna woodland vegetation.

In the uniform high temperatures of the tropics at low or moderate elevation, the main effects of increasing rainfall and humidity on soil characteristics are, progressively:

1. Speedier breakdown of humus, leading to smaller quantities and poorer distribution of organic matter in the soil profile. In the wettest climate, organic matter is completely lacking in the lower horizons.

2. Less and less reserves of undecomposed minerals such as aluminosilicates of K, Na, Ca and Mg (feldspars), etc.

3. More intensive leaching of the clay fraction in the upper horizons and its deposition in the lower horizons.

4. Increasing proportion of kaolinite and oxides of iron and aluminium in the clay fraction, with reduction in montmorillonite and mica. In extreme examples of ferralitic soils, the clay fraction consists entirely of kaolinite and oxides.

5. Lower base saturation and cation exchange capacity (at least in the lower horizons).

6. Increasing quantities of free iron.

7. Decreasing ratio of silica/sesquioxides in the clay fraction.

These progressive effects can be seen in the sequence of soils from the brown soils of the arid areas near the Sahara to the ferralitic soils of the humid equatorial zone. Normally, each soil type grades imperceptibly into the next and, especially in the series of ferruginous tropical-ferrisols-ferralitic soils, which are commonly characterized by the reddish colour resulting from iron oxides and would be included in the broad category of "tropical red earths," the dividing line is somewhat arbitrary. (Ferrisols form a soil type which is intermediate between ferruginous tropical and ferralitic soils.) Further subdivision of each type is usually based on the nature of the parent material.

The two other important soil types mentioned below, the skeletal soils (type 6) and the soils with dark nonkaolinitic clays (type 14) are conditioned by geology or topography rather than by climate. The former is a shallow, stony soil over solid rock, with little or no profile development, and its character is thus determined mainly by the nature of the underlying rock. The

latter occurs in local depressions with no external drainage, in a strongly seasonal rainfall, and forms the lowest soil type in a topographical series or catena, as well as occupying large continuous low-lying areas, as in the "clay plains" of Sudan.

In eastern and central Africa south of the Sahara, the succession of soil types is considerably less simple because of the greater importance of the topographical factor, associated with sharper and more frequent changes in elevation.

The Soils map (centre inset) shows that the most extensive soil types in the savanna are as follows:

Types

12. Brown soils of the arid and semiarid tropical regions
15. Ferruginous tropical soils on sandy parent material
16. Ferruginous tropical soils on miscellaneous rocks
18. Ferralitic soils on sandy parent material
20. Ferralitic soils on miscellaneous rocks
6. Skeletal soils
14. Soils with dark nonkaolinitic clays, in topographic depressions. Also associations of two types together, of which 15/16, 12/16, 12/14 and 16/20 are the most extensive.

The following description of the main soil types of the savanna is based on those of Fournier, 1963, and D'Hoore, 1964.

SOIL TYPE 12. BROWN SOILS OF THE ARID AND SEMIARID TROPICAL REGIONS

Generally with highly saturated nonkaolinitic clay complex.

Approximate equivalent in other soil classifications:[1] xerosols (FAO/Unesco soil map of the world), sols bruns isohumiques (French), calcareous plains' soils (east Africa), mopane soils (Rhodesia), aridisols (U.S. Department of Agriculture).

Brown, or reddish brown soils, usually darkened by organic matter which is well distributed throughout the profile. Usually lacks indurated and impermeable layer of iron oxide. Contains good reserves of undecomposed minerals. Clay fraction predominantly of montmorillonite and mica. Base saturation in B and C horizons more than 50 percent. Cation exchange capacity medium to high (40-60 mEq/100 grammes clay). Often contains free carbonates but not free iron oxide. Ratio SiO_2/Al_2O_3 well above 2.

Occurs predominantly in the semiarid areas of 350 to 500 millimetres rainfall (i.e. subdesert or drier parts of dry tropical climate), with grass steppe or wooded steppe vegetation. Its extension into moister areas is encouraged wherever the parent rock is basic or there is poor external drainage. This type of soil usually has good fertility but is too dry for cultivation except under irrigation. Care must be taken to avoid overirrigation, which causes loss of structure and reduced permeability.

SOIL TYPES 15 AND 16. FERRUGINOUS TROPICAL SOILS ON SANDY PARENT MATERIAL and FERRUGINOUS TROPICAL SOILS ON MISCELLANEOUS ROCKS

Both these types are essentially similar, but are differentiated according to the underlying parent material.

Approximate equivalent in other soil classifications: ferric luvisols or nitrosols (FAO/Unesco soil map of the world), sols ferrugineux tropicaux (French), nonlaterized red earth (east Africa), latosols (general), altisols and ultisols (U.S. Department of Agriculture).

Usually reddish brown soils, with organic matter mainly confined to the uppermost horizon. Usually contain a fair reserve of undecomposed minerals. Often associated with formation of indurated and impermeable layers of iron oxides, variously known as plinthite, massive laterite, murram, ironstone, etc. When the impermeable layer outcrops on the surface, it is known as "cuirasse" or "carapace" in French. The clay fraction consists of more than 50 percent kaolinite and oxides, especially iron oxides. Base saturation usually more than 40 percent, and cation exchange capacity rather poor (20-40 mEq/100 grammes clay). The ratio of SiO_2/Al_2O_3 is about or slightly above 2. Free carbonates are usually lacking, but some free iron oxide is common.

These soils occur mainly in the rainfall areas of 500 to 1 200 millimetres, where there are

[1] FAO, 1968.

distinct wet and dry seasons. The climate is of the dry tropical or semihumid tropical types, and the most typical types of vegetation are wooded steppe and wooded savanna. Fertility is fair only and these soils are very subject to erosion. They are normally of shallower depth than the ferralitic soils (seldom exceeding 2.5 metres), and effective rooting depth is frequently restricted severely by the formation of an indurated plinthite layer.

Soil types 18 and 20. Ferralitic soils on sandy parent material and Ferralitic soils on miscellaneous rocks

These two soils types are closely related and are differentiated on the nature of the underlying parent material.

Approximate equivalent in other soil classifications: ferralsols (FAO/Unesco soil map of the world), laterized red earth (east Africa), latosols (general), oxisols (U.S. Department of Agriculture).

Predominantly red soils with practically no reserves of undecomposed minerals, and with organic matter confined to the surface horizons. Often of considerable depth. Sometimes associated with indurated layers of iron oxides, but less commonly so than the ferruginous tropical soils.

Clay fraction consists entirely of kaolinite and oxides. Base saturation less than 40 percent. Cation exchange capacity very poor (often less than 20 mEq/100 grammes clay). The ratio of SiO_2/Al_2O_3 is usually less than 2. Free iron oxides common, free carbonates absent.

These soil types occur in the humid tropical climate where rainfall is in excess of 1 200 millimetres, frequently under closed forest but also under the moister types of forest-savanna mosaic and savanna woodland. To some extent the lack of fertility is compensated by the depth of the soils and in this respect they may be more suitable for forestry than for agriculture.

Soil type 6. Skeletal soils, mostly rock debris with pockets of soil

Approximate equivalent in other soil classifications: lithosols (FAO/Unesco soil map of the world) but note that in that classification lithosols are defined as being only 10 centimetres or less in depth, entisols (U.S. Department of Agriculture).

Shallow soils, not more than 30 centimetres deep, above a continuous layer of solid rock. Very stony, with little or no development of horizons within the profile. Sometimes subdivided according to the nature of the underlying rock, which may include impermeable plinthite layers formed pedologically, as well as true geological rock.

Soil type 14. Soils with dark nonkaolinitic clays

Confined to topographic depressions, occurring in semiarid areas with a marked seasonal distribution of rainfall.

Approximate equivalent in other soil classifications: vertisols (FAO/Unesco soil map of the world), black cotton soils (east Africa), " Mbuga " (east Africa), " Dambo " (Zambia).

Dark grey or black clays, at least in the uppermost horizon, cracking in the dry season. Layers of accumulation of calcium carbonate frequent. Reserves of undecomposed minerals often considerable. The clay fraction is predominantly of the montmorillonite and mica type. Base saturation over 50 percent, mainly of bivalent cations.

This soil type is associated with topographic depressions in which lack of external drainage is associated with poor internal drainage, in climatic conditions where there are sharply contrasted alternating wet and dry seasons. Fertility is usually very good, but the poor drainage and difficult structure make cultivation difficult, except with special and expensive site preparation techniques.

Appendix 4

ADDITIONAL SPECIES, INCLUDING ORNAMENTALS, FOR PLANTING IN AFRICAN SAVANNAS

Most of the following species are suitable for planting in Climatic types 3 and 4, dry tropical and semihumid tropical. They would not be suitable for planting in type 2, the subdesert, except with irrigation or ground water.

Species	Uses [1]	Remarks	Species	Uses [1]	Remarks
Acacia auriculaeformis	F		*Jacaranda mimosaefolia*	O	
Acacia campylacantha	F		*Khaya senegalensis*	T	
Albizia lebbek	O		*Mangifera indica*	Ft, Sh	
Borassus aethiopum	P, O		*Melia azedarach*	O	
Cassia fistula	O		*Moringa oleifera*	O	
Cassia nodosa	O		*Parkinsonia aculeata*	Sh	
Casuarina equisetifolia	P, Sh	Especially suited for planting on sterile coastal sands, with exposure to sea winds.	*Peltophorum pterocarpum*	O	
Cordia sebestina	O		*Pterocarpus angolensis*	T	The outstanding cabinet wood of the savanna, with a well deserved worldwide reputation. Numerous attempts to grow it in plantation have met with very little success.
Delonix regia (syn. *Poinciana regia*)	O				
Euphorbia tirucalli	Sh	Propagated from large branch cuttings. Makes a useful stock-proof hedge in dry areas. Contains latex which is intensely irritating to the eyes, so needs careful handling.	*Samanea saman*	Sh	
			Sapindus saponaria	Sh	
			Syzigium cumini	Sh	Best suited for low elevations near coast.
			Tamarindus indica	Sh	
			Terminalia catappa	Sh	Best suited for low elevations near coast.
Ficus spp.	Sh	Most species can be propagated from large branch cuttings.			

[1] F = Fuel; Ft = Fruits; O = Ornamental; P = Poles; Sh = Shade or shelter; T = Timber or sawlogs.

SOIL STERILIZATION WITH METHYL BROMIDE

The following notes on sterilization of nursery soil with methyl bromide are adapted from Zambian practice as described by Allan and Endean, 1966.

One of the best methods of soil sterilization is fumigation with methyl bromide gas. The principle of fumigation is to facilitate an even distribution of the gas throughout the soil by releasing the gas under a plastic sheet stretched over a soil clamp, the gas diffusing slowly through the soil.

For sterilization, the soil should be formed into clamps about 13.7 metres (45 feet) long, 3-3.7 metres (10-12 feet) wide and no more than 23-30 centimetres (9-12 inches) deep. A clamp 3 metres × 13.7 metres × 23 centimetres (10 feet × 45 feet × 9 inches) will fill approximately 10 000 pots.

Holes should be made at intervals along the top of the clamp from the top to base to allow better diffusion. The soil should then be thoroughly wetted by saturating the clamp the day before sterilization so the water can percolate throughout, leaving the soil moist when fumigation begins.

If the soil is treated for seed-beds, it is a good idea to place the used bed covering (i.e. vermiculite, sand, charcoal) in sacks on top of the soil in the clamp. The bags help to hold up the sheet and allow diffusion while the material in them is also sterilized. In addition to, or in place of, soil bags, lengths of vitafoam (expanded polyfoam) measuring about 15 centimetres (6 inches) square by 3 metres (10 feet) length are thrown across the clamp at intervals to hold the sheet clear of the soil surface.

The next step is to position the bromide delivery applicator tubes. The dosage currently applied is 9 one-pound cans for a clamp 10 feet × 45 feet × 9 inches, or one pound per 37.5 cubic feet (≈ 1 cubic metre) although recent research indicates that a dosage of about one pound per 100 cubic feet (2.8 cubic metres) of soil may be sufficient. The cans contain liquid methyl bromide under pressure which becomes gaseous when the pressure is released. The gas is led from the can into the clamp by an applicator tube. Three applicator tubes are placed at equal intervals along the clamp, leading from outside to the top of the heap of soil where their ends are placed in tins sunk in the soil to aid dispersion. The end of the tube in the can should be weighted with stones otherwise it thrashes around when the gas is released.

The whole clamp is then covered with "Verpak" heavy duty polythene sheeting (black sheeting is more supple and lasts longer) and sealed around the edges and over the entry of the applicator tubes. The sealing is done by digging a narrow trench 20-23 centimetres (8-9 inches) deep around the whole clamp laying the edge of the sheet in the trench with about 6.6 centimetres (3 inches) of the edge showing outside, then filling the trench on top of the sheet with wet soil tamped with a stick. This sealed edge *must be gas tight*, hence the wet soil and tamping. One can is placed on each applicator and the gas released as shown in the operating instructions. Each can is held in a rubber gloved hand above the level of soil in the clamp so that the last part of the contents can run in. As soon as the can ceases to hiss it is shaken to check that it is empty, it is removed and replaced by a second and finally a third giving a total of nine cans for the clamp. A can takes about two to three minutes to empty.

In warm weather the sheet will inflate when the contents of all cans have been injected; it will then gradually deflate as the gas percolates into the soil. In cold weather the liquid does not evaporate so well and the sheet may not inflate.

The recommended periods for which soil should be left covered in the clamp are:

Cold weather (15°C and below)	3 days
Warm weather	2 days

The soil may be used immediately after removal from the clamp.

Methyl bromide is a poisonous gas and should be handled with care. All workers involved with its use should wear protective clothing and rubber gloves. It is odourless. Some proprietary products include a small percentage of a strong-smelling substance such as Chloro-Picrin to warn operators in case of a leak.

NURSERY IRRIGATION AND WATERING

The following outline is not meant as a guide for final design of an irrigation system, but is intended only as general information on nursery irrigation planning. The principal points discussed are water source, pumping and delivery methods, and sprinkler systems.

Useful definitions [1]

Head of water

The height of the water surface above the delivery point expressed in metres or feet or the equivalent pressure.

Frictional head

The drop in pressure due to friction as water is passed through a pipe, commonly expressed in metres or feet.

Suction head

The vertical height in metres through which a pump must lift (or suck) water.

Delivery head

The actual vertical distance in metres between the pump and the point of delivery.

Water source

Type of source

Any water source capable of providing water of suitable quality and in sufficient quantity may be used for nursery irrigation and watering. Generally, the most reliable sources are permanent streams, ponds, and reservoirs. Municipal water is expensive and may have an excessive chlorine content. Where the water table is accessible and can provide water in sufficient quantities, wells can be excellent sources, but may require installation of expensive pumping equipment.

Water quality

The water used should have a pH of less than 7, should be relatively free of particles and debris, and should have a low total salt content (see p. 97). In particular it should be free from high concentrations of the carbonates of calcium, magnesium and potassium, the chlorides of sodium and potassium, and the sulphates and phosphates of calcium (Paul, 1972). The levels of toxicity of these salts will vary with the sand/clay fractions of the nursery soil mixture. In addition to the total quantity of dissolved salts which affects the diffusion of water from the soil into the plant roots, the balance between individual constituents is also important, since an excess of any one element may be toxic.

Water quantity

It is mandatory that water be available in adequate quantities throughout the nursery season. Calculation of the total water requirement should be made, not from the average, but from the peak demand period, i.e. at its lowest level in the dry season the source must be capable of supplying the total demand at a time when the plants are at their greatest size and evapotranspiration is at its highest level.

As a rough guide to net water requirement in, say, the last month before the anticipated date of planting, an estimate of local potential evapotranspiration (E_t) may be made from in-

[1] Paul, 1972.

formation available from the meteorological services. At present such estimates must often be crude, since they are based on extrapolation from climatic stations some distance away from the nursery, but, as the scatter of stations and the variety of measurements improve, it will be possible to predict local potential evapotranspiration with an acceptable standard of accuracy. Though actual evapotranspiration (E_a) is likely to be appreciably less than potential, especially when irrigation is deliberately reduced in an attempt to harden off the plants, it is wise to use the higher E_t figure as an insurance. This should be multiplied by a factor, which is essentially a measure of the efficiency of the particular irrigation system, to account for water losses through surface evaporation and run-off, percolation, wind blow and atmospheric drift. This factor is usually within the range of 1.2 to 1.4, depending on climate, soil type and method of irrigation. If, for example, the monthly E_t is estimated at 200 millimetres, the water loss factor at 1.3, and the size of nursery beds at 1 hectare, it will be necessary to count on the availability of $1.3 \times 0.200 \times 100 \times 100 = 2\,600$ cubic metres of water during the month.

The amount of water actually applied at any one time will vary with the soil infiltration rate, weather conditions, and size of the plant. During the germination period, frequent light watering is required to keep the seed-beds moist, but not saturated. As the plants get larger, the total quantity of water applied is increased and the frequency of application is reduced. Under similar weather conditions, a light, sandy soil demands more water than a heavier soil.

Pumping methods

An ideal method of delivering water from the source to the nursery is by gravity feed, usually consisting of a network of canals and irrigation ditches, and sometimes pipes. When gravity feed is not feasible, one or more pumps are required. Hydraulic rams, reciprocating and hand-operated pumps are briefly discussed although they have such a small flow that they find application only in the smallest forest nurseries. Centrifugal pumps are by far the most versatile and the most used for operating irrigation systems.

Hydraulic ram

Where there is a sufficiently sharp stream gradient to drive the ram, the hydraulic ram can be used to raise a small quantity of water to a high level. It is inexpensive to purchase and maintain as it requires no engine, no fuel, has only two moving parts, and operates ceaselessly (Paul, 1972).

Reciprocating pump

The reciprocating pump is driven by either an electric, diesel, or petrol power unit and is suitable for moving water over long distances to a high delivery head. In general the suction head should not exceed 6.1 metres (20 feet) (Paul, 1972).

Centrifugal pump

Centrifugal pumps can be of either the horizontal or deep well types. The horizontal centrifugal pump, so called because of the horizontal position of the impeller shaft, is commonly used for pumping directly from a water source into the irrigation network. It is very efficient for lifting large volumes of water provided the suction head does not exceed about 4.6-6.1 metres (15-20 feet) and offers the advantages of smooth flow and good control of flow.

The deep well pump has a vertically oriented drive shaft and is especially adapted to lift water from wells in which the water level is far below the ground surface (Molenaar, 1960). The submersible pump is a variation of this type which offers potentially higher efficiency. Both deep well and horizontal centrifugal pumps require power units.

Hand-operated pumps

Hand-operated pumps are still used in some small nurseries, but they are rapidly being replaced by small, inexpensive power-operated ones. A two-man rotary pump capable of reaching pressures of up to 1 406 kilogrammes/square centimetre (20 lbs/square inch) and extracting water from wells 18.3 metres (60 feet) deep is used in nurseries of up to 50 000 trees. Semirotary pumps operated by one man are used in small nurseries of not more than 30 000 trees. Pressures of 1 406 kilogrammes/square centi-

metre (20 lbs/square inch) can be developed, but not more than three coupled spray lines of 4.6 metres (15 feet) long 5.1-centimetre (2-inch) diameter pipe with 35 jets should be operated at one time (Fishwick, 1966).

Water storage

The main reason for water storage in forest nurseries is to provide the large flows required for irrigation (especially surface) when the water source cannot yield it. This may be the case, for instance, with a well that supplies the total amount of water required during a period (say 24 hours), while the irrigations are carried out with a higher flow during a much shorter period.

Additional advantages of storing water are to have a supply should maintenance be required on the mainline system, and to allow for the settling of detritus and foreign matter which could clog sprinkler nozzles. Both ponds and tanks can be used for water storage.

Pipeline assemblage

Types of systems

The system of pipes which delivers water to and throughout the nursery central growing area can be either stationary, semiportable, or portable. In the stationary system the main pipes and sprinkler laterals remain in a permanent position and are often buried. The lack of flexibility makes this system impractical for most forest nurseries.

A more common method consists of a stationary main line, either stationary or portable submain lines, and portable sprinkler lines.

In this semiportable system the main delivery line may be buried and brought to surface at the edge of the growing area where it is connected to the submain lines which are spaced throughout the nursery. The sprinkler lines are connected to the submains and spaced to give a uniform water distribution.

Temporary nurseries may require use of a completely portable system where not only the submains and sprinkler lines are portable but also the main line and even the pumping plant.

Materials and accessories

The tubing used should be lightweight (i.e., aluminium), quick-coupled pipe with special slip-joint connections, making handling and moving easy operations. The diameter of pipe should be carefully selected in accordance with the size of perforation or nozzle used, the water head developed by the pump or elevated reservoir, and the loss of head due to friction on the inner surface of the pipe. The frictional head is independent of the working pressure but is related to the square of the water velocity, the inner diameter of the pipe, the material of which the pipe is constructed, and is directly proportional to the length of the pipe. The irrigation pipe system must be calculated so that the difference in pressure, resulting from frictional losses or sloping land, between the first and last sprinklers does not exceed 20 percent of the fixed operating pressure. Where pressure differences are greater, it is necessary to install pressure regulators in different parts of the system to maintain the pressure within the fixed limits. Other useful additions to the pipeline system include portable pressure gauges and flow meters at each pump intake. These will enable the measurement of actual quantities and rates of water application. Consideration should also be given to installation of filter cones or a water screening device to reduce fouling of the system by debris.

Methods of application

There are basically two main irrigation methods used in forest nurseries: the surface method, and the overhead method. Surface irrigation can be of the furrow type where the water is channelled through the beds in small ditches or furrows, or the flood type where water is let into the bed from one or more entries and the entire bed is flooded. Both types of surface irrigation are relatively inexpensive to operate but require good land levelling and skilled labour. Furthermore, they are inefficient in water use and may lead to an undesirable lengthening of the tap root due to a tendency to overwater.

Overhead sprinkler irrigation is generally better. Sprinklers can be of either the perforated

pipe, nozzle line, or rotary types. The choice of method will depend primarily on the uniformity of coverage and precipitation rate desired. The precipitation rate is a factor of operating pressure, sprinkler spacing, and size of perforation or nozzle. Large nozzles at low pressures may result in large, damaging droplets while too small droplets will atomize and can be easily windblown.

Perforated pipe

This system consists of lightweight pipes in which small holes have been drilled in such an arrangement as to cause the water to be distributed on both sides of the pipe. As the perforations are quite small, clean water is essential. The width of the strip covered varies with pressure from about 4.3 to 15.2 metres (14 to 50 feet). The system can be operated at pressures of 0.3 to 1.0 kilogrammes/square centimetre (4 to 15 lbs/square inch). Application rates are rapid, from 1.3 to 5.1 centimetres (0.5 to 2.0 inches) per hour so nursery soils must be highly permeable (Molenaar, 1960). Special consideration must be given to the uniformity of water coverage in nurseries raising potted stock because of the restricted lateral movement of soil water.

Nozzle lines

Nozzle line systems are similar to the perforated pipe method with the exception that jets, or nozzles, are screwed into the pipe. A basic nozzle line system consists of one or more 2.5- to 7.6-centimetre (1- to 3-inch) diameter pipes to which is attached a single row of small nozzles spaced at uniform intervals of from 12.7 centimetres to 0.9 metres (5 inches to 3 feet) along their entire length. The nozzle lines are supported above ground on posts 0.6 to 1.8 metres (2 to 6 feet) high and can be rotated by hand or by an automatic oscillator through the desired angle between 90 and 180 degrees. Normal coverage extends from about 5.5 to 7.6 metres (18 to 25 feet) on either side of the line, and operating pressures vary from 1.8 to 4.9 kilogrammes/square centimetre (25 to 70 lbs/square inch).

A variation which is generally stationary consists of a number of rows of jets spaced around the pipe as well as lengthwise. Coverage with this system, as with the single oscillating line, is good. Nozzle line systems are well adapted for use in tree nurseries.

Rotating sprinklers

Systems which discharge water through rotating sprinklers can be either of the rapidly whirling or slowly revolving single or multinozzle type. Rotating sprinklers are becoming increasingly popular in large nurseries. Operating pressures vary widely with the size of nozzle from 1.8 to 4.9 kilogrammes/square centimetre (25 to 70 lbs/square inch) and more. Rotating sprinklers are generally more tolerant of small particles of debris than other systems. Because of the circular pattern of water distribution, special care must be given to arranging the sprinklers so as to give the most uniform coverage. A triangular pattern may result in the best coverage, but a rectangular one may be more practical in most nurseries. Sprinkler intervals are generally from 12.2 to 18.3 metres (40 to 60 feet).

Hand watering

On small nurseries with up to 10 000 trees, installation of expensive pumping equipment is not warranted, and watering is done with fine rose watering cans or hand-operated mist sprayers (Fishwick, 1966). Even in many large nurseries with mechanical irrigation, hand watering is still used in the germination beds when lightweight seed is sown or when the seed-beds are shaded or protected against heavy rains by a low cover which would restrict mechanical watering. Hand watering has the advantages of simplicity and instant control, but requires skilled operators to achieve uniform coverage.

RECOMMENDATIONS FOR FIRE PROTECTION OF INDUSTRIAL PLANTATIONS

The following recommendations are based on a report by Cheney, 1971, concerning fire protection in industrial forest plantations in Zambia.

Fire hazard and hazard reduction

A principal fire hazard in savanna industrial forest plantations is the rapid build-up of fuel from leaf and needle fall, prunings, and noncommercial thinnings. Both the amount and distribution of fuel are important.

The rate of spread of a fire and its intensity are directly proportional to the weight of fire fuel on the ground (i.e. fuel less than 0.6 centimetres or 0.25 inches in diameter).

The weight of heavy log fuels on the ground adds indirectly to the fire intensity, but adds very significantly to the duration of heat output, and to the difficulty of fire line construction, and fire suppression generally. The distribution of fuel affects the flame height and, to a certain degree, the tendency of the flames to spread into the tree crowns and develop into a crown fire. The quantity and distribution of fuel on the ground are the only fire behaviour factors over which man has any control.

Piling of slash

Slash should not be piled within the plantation compartments. This practice only reduces the fire hazard if the area cleared is kept free of all fuel, and this is not feasible. On the other hand, it complicates fire fighting by creating an obstacle to fire fighters and further complicates control burning by increasing the duration of fire at the pile, and trees either side of the slash pile are liable to butt damage.

Noncommercial thinning

Heavy noncommercial thinnings in the early stages of plantations leave a mass of log and fire fuels on the ground, make the job of fire line construction very difficult and drastically increase the fire intensity.

Where markets are not available, thinnings should be killed and left standing. Although such thinnings look hazardous, from a fire protection point of view it is far better to have the fuel standing rather than lying on the ground. However, research is needed to determine the most effective and economic methods of poisoning standing trees.

Control burning

In control burning the behaviour of fires prescribed for a particular area is defined so that no damage to the standing crop occurs. The burning is carried out under accurately defined weather conditions to achieve the desired fire behaviour.

Where fuels are heavy, control burning should not aim at the complete removal of fuel in one operation, as the conditions required to do this will cause the fire to be too intense and will result in damage to trees. Heavy fuels can, however, be removed by several successive burns over the same area — each burn removing a proportion of the fuel bed. Control burning in old stands should be carried out periodically to keep the fuel quantity below 12½ tons per hectare (5 tons per acre).

Control burning should be carried out late in the wet season or early in the dry season and after the hottest part of the day, when the burning conditions are becoming milder. It should be planned to extend over the maximum period available for burning.

Although burning techniques in any given area must depend on local experience, the following prescriptions should be appropriate for most conditions:

1. Carry out test fires in advance of the main burning operation, to determine the rate of spread of the fire and the time of night when fires are self-extinguishing. (During the height of the dry season fires will burn all night.)
2. Do not burn if the forward spread exceeds 60 centimetres (2 feet)/minute.
3. Burn when the wind is calm or less than 8 kilometres or 5 miles per hour in the open.
4. Do not burn if the relative humidity drops below 35 percent during the day.
5. Commence burning in the afternoon when the relative humidity rises above 50 percent.
6. Do not burn when the annual grasses become fully dried.

The timing of the first control burn in a young plantation may be critical. For pine plantations, a mean height of 8 to 11 metres corresponding to an age of six to eight years, is likely to be an average figure, but this will vary considerably according to local conditions.

A trial in Zambia showed that stands of this size survived a fire burning about 12½ tons/hectare (5 tons/acre) of fuel and spreading at about 60 centimetres (2 feet)/minute. The first control burn should follow the first pruning, and in the timing of this pruning operation fire control considerations may outweigh silvicultural ones.

Firebreaks

The purpose of firebreaks is to provide access through the forest and to provide a fuel-free barrier to fire.

Ideally, a firebreak should consist of a clean graded road with trees planted up to the edge. When the trees close canopy they will suppress grass growth adjacent to the road. If they are planted back from the edge of the road, then grass will grow, and the strip either side of the road is committed to the expense of ploughing or mowing.

Firebreaks should be oriented perpendicular to the direction of the prevailing wind during the fire season.

Ploughed firebreaks

Firebreaks which are maintained by ploughing are very often unsuitable.

Heavy grass is generally not removed by ploughing, but is mixed in with the soil and provides fuel which will not stop a low-intensity fire burning under very mild conditions. Also, ploughed firebreaks do not allow rapid access along them, and rapid access is essential if initial attack is to be successful.

Wide firebreaks

While wide firebreaks give a feeling of security, they are generally not wide enough to be effective against a high intensity fire which is throwing spot fires; they channel the wind flow along the firebreak and cause severe turbulence on the edge of the plantations; and they are expensive and costly to maintain.

Green firebreaks

A green firebreak should be an area with complete canopy closure to prevent grass growth, and maintained free of litter by periodic burning. Where control burning is practised, green firebreaks become largely redundant as they receive the same treatment as the plantation. Where commercial species are suitable for green breaks, these should be used in preference to any non-commercial species. Green breaks of fast growing eucalypts have an added advantage in pine areas as they reduce the wind speed in the forest, particularly when the pines are young.

Detection and reporting of fires

A sound fire detection system, usually based on fire towers, is essential for good fire control. Fire towers should be located to provide the maximum area seen from the least number of points.

The sites selected should allow good visibility, should be the highest available, and should allow triangulation with other towers so that accurate cross bearings can be obtained. Each tower should be equipped with an alidade, binoculars and a radio/telephone.

Fire fighting equipment

Fire fighting equipment should be related to the job to be done and the people who are to use it and should provide a rapid, mobile, initial attacking force.

Adequate stocks of hand tools must be maintained. Basic to any fire fighting programme are: McLeod tools (a combination rake and hoe), knapsack sprays, shovels, axes, brush hooks, illumination equipment, water bags, back firing torches, and first aid supplies. Water tankers should also be available.

Fire danger assessment

Information on the conditions under which fires are most likely to start, and their behaviour once started is essential for effective fire control. Such information is normally available in a fire danger rating system, which integrates the four major meteorological factors affecting fire behaviour (temperature, relative humidity, wind speed, and long and short-term drought effects). An example is the McArthur Forest Fire Danger Meter.

Fire control organization

A fire plan should be considered an essential part of the management plan of any substantial area of plantations in the savanna and the plan should include provision for the establishment and training of a fire control section to implement it.

The fire control section would be responsible for control burning operations, maintenance of firebreaks, assessment of fire hazard, maintenance of fire towers, fire reporting, communications and the initial fire suppression attack.

CONVERSION FACTORS

LENGTH

1 kilometre (km) = 0.62137 miles
1 metre (m) = 3.280833 ft
1 centimetre (cm) = 0.3937 in.

1 mile = 1.609347 km
1 foot (ft) = 30.48006 cm
1 inch (in.) = 2.540005 cm

AREA

1 square metre (m^2) = 10.76387 ft^2
1 hectare (ha) = 2.471044 ac

1 square foot (ft^2) = 929.034 cm^2
1 acre (ac) = 0.404687 ha

WEIGHT

1 kilogramme (kg) = 2.204622 lb
1 gramme (g) = 0.035274 oz

1 pound (lb) = 453.592 g
1 ounce (oz) = 28.34953 g

1 metric ton = 1.102 short tons = 0.98 long tons

VOLUME

1 cubic metre (m^3) = 35.3145 ft^3

1 cubic foot (ft^3) = 28.317 cm^3

1 litre = 0.264 gallons (U.S.) = 0.220 gallons (Imperial)

PRESSURE

1 kg/cm^2 = 14.2 $lb/in.^2$

1 $lb/in.^2$ = 70.3067 g/cm^2

DENSITY

1 kg/m^3 = 0.062428 lb/ft^3

1 lb/ft^3 = 16.0184 kg/m^3

TEMPERATURE

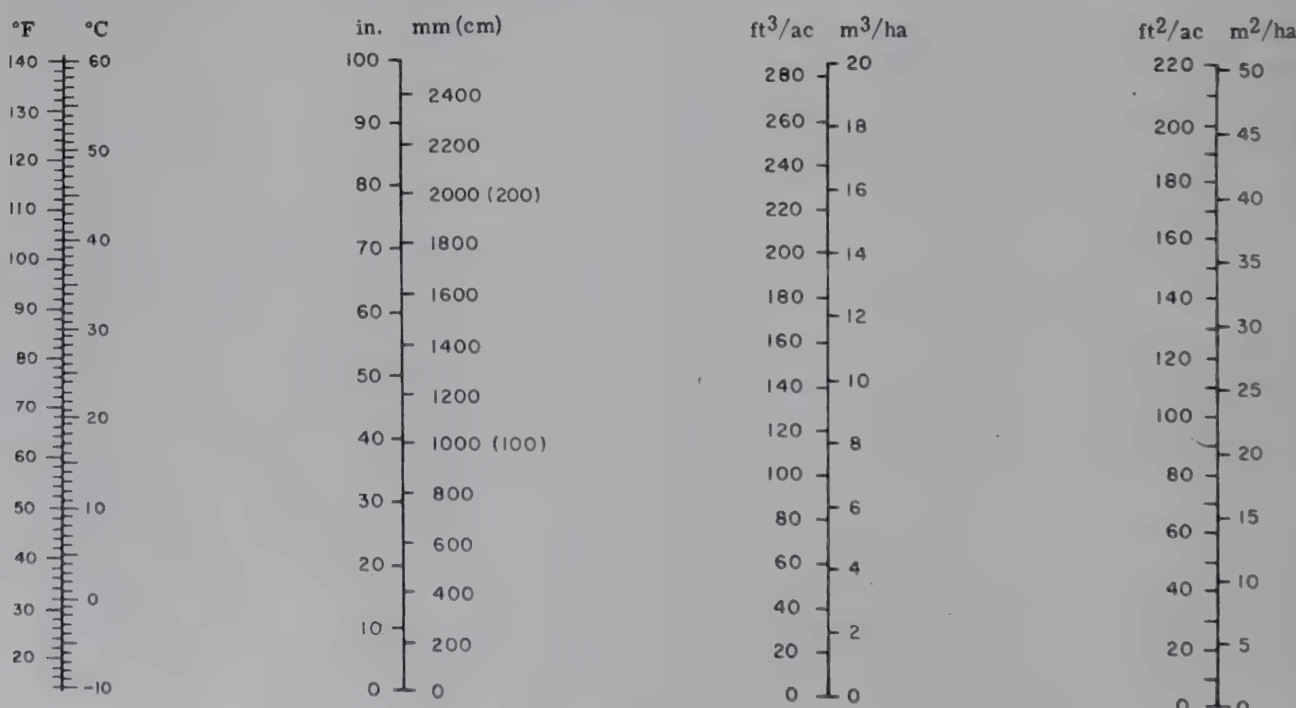
$°C = 5/9\ (°F - 32)$

$°F = 9/5\ °C + 32$

GROWTH

1 m^2/ha = 4.3560 ft^2/ac
1 m^3/ha = 14.2913 ft^3/ac

1 ft^2/ac = 0.2296 m^2/ha
1 ft^3/ac = 0.06997 m^3/ha



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